Hydrogeomorphic Evaluation of Ecosystem Restoration and Management Options for

Conboy Lake National Wildlife Refuge

Prepared For:

U. S. Fish and Wildlife Service
Region 1
Vancouver, WA

Greenbrier Wetland Services
Report 14-07

Adonia R. Henry
Mickey E. Heitmeyer

October 2014

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Prepared For:

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EXECUTIVE SUMMARY

Conboy Lake National Wildlife Refuge (CLNWR) includes 6,380 acres of diverse wetland and upland habitats in the Glenwood Valley, Klickitat County, Washington. The dominant landform characteristic of the refuge is poorly drained sedimentary deposits from Mount Adams that formed a shallow groundwater aquifer and supported extensive wetlands in the historical Camas Prairie and Conboy Lake. Snowmelt and associated streamflow from Mount Adams drove surface water hydrology within the valley. Surface water from Bird, Frasier, Chapman, and Holmes creeks meandered through the valley foothills leaving confined channels to sheetflow across the landscape when it reached the relatively flat valley floor. Complex groundwater movements in the surrounding basalt dominated uplands and under the sedimentary deposits created recharge and discharge areas within the watershed that interacted with surface water flows.

CLNWR was established during 1965, after which existing agricultural "improvements" were initially modified, and later redesigned to develop infrastructure to manage wetland habitats for migratory birds. Prior to anthropogenic developments at and surrounding CLNWR, water levels in the Klickitat Subbasin were characterized by seasonal, annual, multidecadal, and long-term fluctuations in the depth, duration, and extent of flooding. Conboy Lake ranged from an estimated maximum of about 6,000-7,000 acres during wet years to a maximum of 3,000 acres during dry years. Water levels declined during the summer as precipitation and snowmelt decreased and evapotranspiration increased. During wet years about 1,000 acres remained flooded during the summer, whereas, during dry years the extent of flooding was reduced to about 400 acres. Drainage designed to enhance agricultural practices in the Glenwood Valley at and surrounding the refuge greatly altered this ecosystem by reducing the duration and extent of flooding.

During 2014, the USFWS completed a draft Comprehensive Conservation Plan (CCP) for CLNWR, which articulates the long-term management direction for the refuge. Implementation of restoration and management actions is being facilitated by this hydrogeomorphic (HGM) evaluation that assesses the historical and current ecosystem. This report uses the HGM approach to synthesize available historical and current information about: 1) geology and geomorphology; 2) soils; 3) topography and elevation; 4) hydrology and climate; 5) land cover and vegetation communities; 6) key plant and animal species; and 7) physical anthropogenic features of the refuge and surrounding lands with the following objectives:

1. Identity the Pre-settlement (pre-European contact) ecosystem conditions and the ecological processes supporting them at CLNWR.

2. Evaluate changes in the CLNWR ecosystem from the Pre-settlement period with specific reference to alterations in hydrology, topography, vegetation community structure and distribution, and resource availability for fish and wildlife species.

3. Identify restoration and management options plus ecological attributes needed to successfully restore and/or manage specific habitats and conditions at CLNWR.

Located at the transition zone between the Eastern Cascade Mountains and the Columbia Plateau, the Glenwood Valley has a complex history of geologic processes, including eruptions of Columbia River Flood Basalts, folding and faulting due to plate tectonics, Quaternary basalt flows from Mount Adams, and glaciofluvial and alluvial deposition throughout its geologic history. Wanapum basalt overlies Grand Ronde basalt to the south of Glenwood Valley. Basalt and andesite lava flows from Mount Adams occur to the west and north of the valley and overlie older Columbia River Flood Basalts and/or Quaternary basalt flows from Mount Adams. CLNWR is located within a Holocene and late Pleistocene lahar from Mount Adams. Soils range from poorly drained clay loams on the valley bottom to well drained sandy loams on mountain slopes.

The climate at CLNWR is characterized by hot, dry summers and cold, relatively wet winters with annual precipitation averaging about 33 inches/year. However, annual precipitation is highly variable, ranging from 46 to 152% of the mean. Snowpack on Mount Adams is also highly variable with annual peak snow water equivalent ranging from 10.5 to 86 inches. Historical water levels peaked during May or June as a result of snowmelt runoff and declined throughout the summer. Cooler temperatures and local precipitation during the fall resulted in increased water levels beginning during October or November and persisting through most winters. In addition to seasonal patterns of flooding, The refuge has evidence of long recurring 15-20 year patterns of peaks and lows in regional precipitation, runoff, and water levels prior to 1963 contributing to a relatively long wet-dry cycle of 30-40 years. Since 1963, relatively short wet/dry cycles of 5-10 years have occurred in the region. Paleoclimate studies also suggest longer term multidecadal and centennial-scale variations in climatic conditions.

Historical vegetation communities on the refuge ranged from ponderosa pine-upland meadows to extensive seasonally flooded wet meadows and nearly permanently flooded wetlands at Conboy Lake. The gradations of vegetation communities varied temporally and spatially depending on abiotic conditions and included open water/submerged aquatic vegetation, semi-permanently flooded emergent marshes, seasonally flooded wet meadows, riparian meadows, ponderosa pine forests with abundant native bunchgrasses and pine grass, and mixed pine-fir forests. Wetlands were maintained by spring runoff, poorly drained clay loam soils, local precipitation, and discharge of groundwater through springs. The spatial and temporal variation in water table levels controlled the distribution of native vegetation in wet meadows based on water-stress and oxygen-stress tolerances of individual plant species.

Native Americans inhabited the Glenwood Valley as a temporary subsistence camp during the summer when they harvested and utilized abundant natural resources. Europeans first settled the valley during 1872; early residents grazed domestic livestock and harvested timber on the surrounding hills. Extensive modifications to the hydrology of the Glenwood Valley began during 1911 when European settlers constructed Camas Ditch and channelized Outlet Creek to drain the Camas Prairie wetlands and Conboy Lake. Creeks draining into the Glenwood Valley were also channelized, which further reduced overbank flooding and sheetflow. Water appropriations and stream diversions were made on Hell Roaring Creek to irrigate hay lands. Drainage ditches and other hydrologic alterations reduced the historical "lake" from a maximum annual extent of about 6,000 to 7,000 acres down to a maximum of 3,000 acres. Drainage improvements caused the lakebed to go completely dry compared to an estimated 400 to 1,000 acres that historically remained flooded each year during the late summer. During the 1977 drought, Camas Ditch and Outlet Creek were dry for nearly their full lengths. These observations suggest that the canal and ditch system effectively increased the rate of surface and subsurface water drainage of historical wetlands.

Early water management at CLNWR was mostly limited to cleaning and maintaining existing ditches. Active manipulation of water levels for wetlands management objectives began during 1976 and wetland development actions increased during the 1980s. Although wet meadow and marsh species began to replace reed canary grass and some upland species that had invaded Conboy Lake, high berms and ditches originally designed for agricultural purposes still hindered restoration of wetland processes. During 1998, USFWS began filling ditches and lowering high berms to allow increased sheetflow, while still allowing the potential to hold water during dry years. Currently, eighty water control structures within the refuge are used to manage approximately 1,100 acres of seasonally flooded wetlands. Water drawdowns are timed to accommodate habitat management objectives and metamorphosis of Oregon spotted frog tadpoles. Drainage ditches, altered sheetflow, fire suppression, and historical grazing of domestic livestock have impacted native habitats at on the refuge.

Given constraints of surrounding land uses, mandates for restoring and managing ecosystem integrity, and opportunities for within-refuge and watershed-scale conservation, we recommend that the future management of CLNWR should consider the following goals:

1. Protect and restore the physical integrity and hydrologic character of the historical Camas Prairie ecosystem;
2. Restore natural surface water flow patterns and, where necessary, manage water flows to mimic spatially and temporally variable natural hydrological conditions;
3. Restore and/or manage for the diversity, composition, distribution, and regenerating mechanisms of diverse, self-sustaining native wetland and upland vegetation communities in relation to hydrogeomorphic landscape position;
4. Provide key resources that mimic natural patterns of resource availability and abundance during appropriate life history stages.

Specific recommendations to meet ecosystem restoration and management goals identified above are fully described in this report.

In addition, future management of CLNWR should include routine monitoring and management-oriented research to determine how ecosystem structure and function are changing. Ultimately, the success in restoring and sustaining communities and ecosystem functions/values will depend on how well the physical and hydrological integrity of the shallow groundwater is protected as well as how key ecological processes and events, especially naturally variable seasonal and annual surface water flows, can be restored or mimicked by management actions. Many recommendations in this report will also increase the resiliency of the refuge by allowing it to better adapt to future climate change. Management actions should be done in an adaptive management context where predictions about resource responses are articulated through objectives relative to specific management actions and then follow-up monitoring is conducted to evaluate ecosystem responses of plant and animal communities to management actions. Especially critical scientific information and monitoring needs for CLNWR include:

1. Key baseline ecosystem data including surface and groundwater attributes, additional soil data, and detailed topographic data.

2. Hydrological data on water use and flow patterns, water levels and duration of flooding within managed wetland units, soil moisture, and water quality; and

3. Long-term changes in plant and animal communities in response to management actions.

Lisa Wilson

INTRODUCTION

Conboy Lake National Wildlife Refuge (CLNWR or refuge) was established during 1965 and contains 6,380 acres of fee-title and 718 acres of conservation easement lands, including diverse wetland and upland habitats in the Glenwood Valley in Klickitat County, Washington (Fig. 1). The refuge has an approved acquisition boundary of 9,245 acres. The relatively flat Glenwood Valley bottom historically supported the vast Camas Prairie and the namesake "Conboy Lake." These wetland habitats were supplied by groundwater discharge and surface water from Bird, Frasier, Chapman, and Holmes creek drainages that originate within the Klickitat Subbasin on the east side of Mount Adams in the Cascade Mountains. The amount and timing of surface water inputs depended on snowpack at Mount Adams, snowmelt and associated runoff, local precipitation, and temperature patterns.

Since its establishment, management of CLNWR has sought to manage water to maintain wetland habitats for breeding and migrating waterfowl and other wetland dependent wildlife. Upland meadows, ponderosa pine, and mixed pine-fir forests support several species of landbirds. Historical land uses (e.g., grazing and haying) involving the drainage of Camas Prairie and Conboy Lake have altered the natural hydrology of wetland habitats within the valley. Water delivery and control infrastructure are used to manage wetland units, but refuge-wide water management is constrained by the incomplete "checkerboard" pattern of U. S. Fish and Wildlife Service (USFWS) refuge ownership.

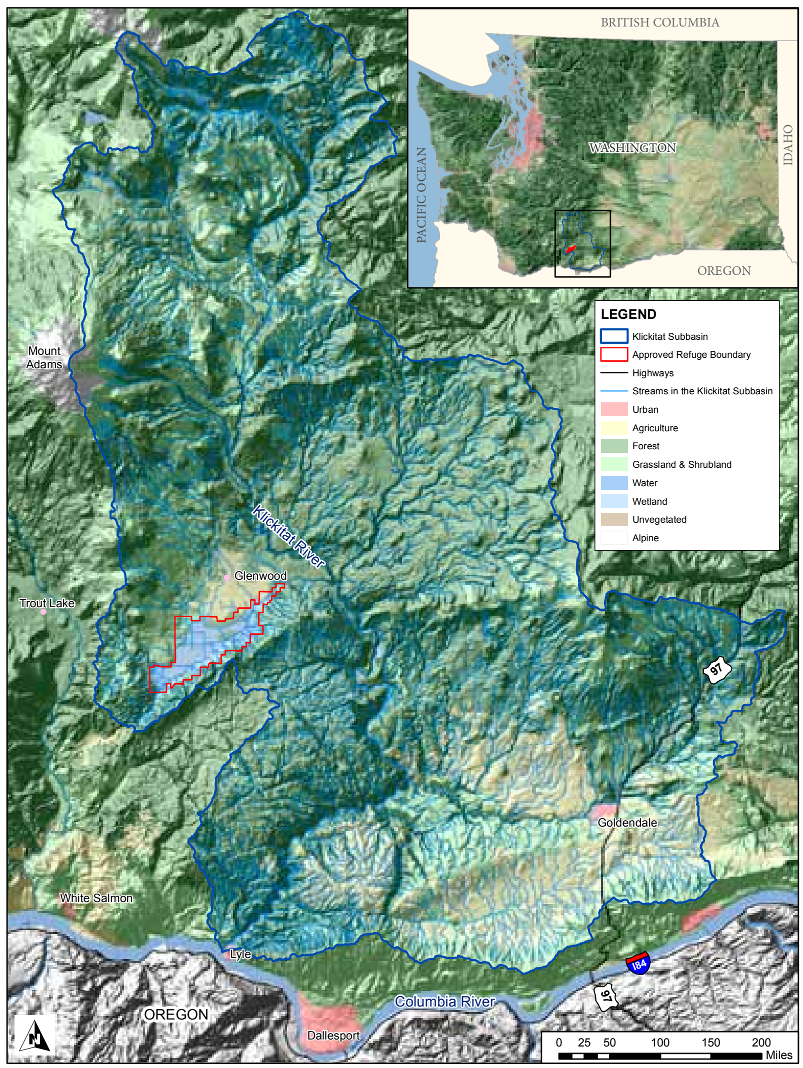

Figure 1. General location of Conboy Lake National Wildlife Refuge, Washington (Landcover from Washington GAP Analysis Program).

During 2014, the USFWS completed a draft Comprehensive Conservation Plan (CCP) for CLNWR (USFWS 2014), which articulates the long-term management direction for the refuge. The CCP includes resource management goals, objectives, and strategies that consider the role of the refuge and its contribution to the regional landscape. Recently, Hydrogeomorphic Methodology (HGM) evaluation has been used to assess ecosystems on other refuges throughout the U. S. and to assist with CCP development and implementation, especially ranges of management alternatives (e.g., Heitmeyer and Fredrickson 2005, Heitmeyer and Westphall 2007, Heitmeyer et al. 2009, Heitmeyer et al. 2010, Heitmeyer et al. 2012). HGM evaluations identify restoration and management options following USFWS policies for NWRs (620 FW 1 and 601 FW 3) that "favor management that restores or mimics natural ecosystem processes or functions to achieve refuge purpose(s)."

This report details the HGM evaluation for CLNWR. The historical condition of the Camas Prairie region and changes to that ecosystem provide an evaluation of biological integrity in accordance with USFWS policy (601 FW3) (USFWS 2001). The HGM approach provides a historical context to understand the physical and biological formation, features, and ecological processes of lands within the refuge and the surrounding region. This historical assessment identifies the natural ecosystem processes (baseline conditions), to evaluate changes that have occurred in the abiotic and biotic attributes of the ecosystem and how these changes have affected ecosystem structure and function. The natural ecological processes that maintained the productive biological communities are the basis for restoration and management options provided in this HGM evaluation, which ultimately assess the capability of the area to restore and/or manage for fundamental ecological processes and resources.

To accomplish this assessment, the HGM utilizes and synthesizes available historical and current information about: 1) geology and geomorphology; 2) soils; 3) topography and elevation; 4) hydrology and climate; 5) land cover and vegetation communities; 6) key plant and animal species; and 7) physical anthropogenic features of the CLNWR and surrounding lands. Historical data are most complete beginning with the 1873-1875 General Land Office (GLO) surveys; however, very few ecological descriptions of the area are available until the refuge was established during 1965.

Objectives for this report are the following:

1. Identify the Pre-settlement (pre-European contact) ecosystem conditions and the ecological processes supporting them at CLNWR.

2. Evaluate changes in the CLNWR ecosystem from the Pre-settlement period with specific reference to alterations in hydrology, topography, vegetation community structure and distribution, and resource availability for fish and wildlife species.

3. Identify restoration and management options plus ecological attributes needed to successfully restore and/or manage specific habitats and conditions at CLNWR.

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HISTORICAL CONBOY LAKE ECOSYSTEM

GEOLOGY AND GEOMORPHOLOGY

CLNWR is located in an area of geologically recent basalt and alluvium on the western edge of Columbia Plateau in the Columbia River Flood Basalt (CRFB) Province where it transitions into volcanics of Mount Adams in the Cascade Mountains. The relatively young CRFB likely overlies oceanic crust and older continental accretions and volcanic islands formed as the North American plate moved west causing the oceanic crust and upper mantle under the Pacific oceanic plate to sink beneath the lighter continental plate. Complex assemblages of highly deformed Precambrian to lower Tertiary continental and oceanic rocks that surround the Columbia Plateau indicate several episodes of continental accretion (Swanson and Wright 1978).

A chain of volcanoes extending from northeastern Washington south under the more recent Columbia Plateau formed as the Okanogan microcontinent was added to North America approximately 100 million years ago (mya) (Alt and Hyndman 1984). By 50 mya, the North Cascade micro-continent added another piece of continental crust to the North American continental plate. This micro-continent contained active volcanoes that continued to erupt until 25 mya, forming the base of the current Cascade Mountains. Eocene (55-35 mya) volcaniclastics in the Cascade Mountains along the western edge of Klickitat County indicate abundant extrusion of volcanics during the early Tertiary (Brown 1979) when the old Western Cascade volcanoes were active. Basaltic and andesitic lavas are interbedded with the volcaniclastics; their distributions are masked by the younger volcanics of Mount Adams and basalts of the Columbia River Group (Brown 1979).

The old Western Cascade volcanoes were inactive from approximately 25 to 15-10 mya (Alt and Hyndman 1984) after which renewed volcanic activity in the Cascades formed the current high Cascade Mountains. Mount Adams is the largest volcano in the Pacific Northwest. Of the Cascade stratocones, it is surpassed in volume only by Mount Shasta (Hildreth and Fierstein 1995). In addition to the central stratovolcano, extensive fields of subdued volcanic centers occur on its heavily forested lowland periphery. The central cone of Mount Adams covers about 232 square miles and the peripheral volcanic fields cover an additional 251 square miles. Basalt and andesite lava flows occur on the western slopes of the Glenwood Valley and overlie older flows from Mount Adams and CRFB. Detailed descriptions and estimated ages of Quaternary basalt and andesite lava flows are explained by Hildreth and Fierstein (1995).

Eruptions of the CRFB began during the period of inactivity in the Cascade volcanoes. Several models have been proposed for the origin of the CRFB. However, "thickness and competency of the lithosphere appear to have played major roles in determining both where the basalts erupted and how they were subsequently deformed" (Hooper 1997:19). The basaltic character of all CRFB flows suggests they were derived from the partial melting of a mantle source (Hooper 1997). The relatively young CRFB are associated with the impingement of a small mantle plume, the Yellowstone hotspot, on the base of the lithosphere near the Nevada-Oregon-Idaho border about 16.5 mya (Hooper 1997). The eruptive activity moved northward to the Washington-Oregon border possibly due to thin zones in the lithosphere. Seismic-refraction measurements indicate the crust under the Columbia Plateau is as much as 7.5 miles thinner than in northern Washington and central Oregon (Hill 1972). A thin horizon at the depth of 62 miles may be present in the upper mantle beneath the Columbia Plateau; this horizon may form the lid to a pronounced low-velocity zone extending to a depth of about 87 miles (Hill 1972).

The Columbia Plateau contains more than 300 individual basalt flows with a total volume of about 42,000 cubic miles. Surficial geology of the Columbia Plateau includes unconsolidated sedimentary deposit (also called overburden) and five basalt formations in the CRFB (Fig. 2) (Vaccaro 1999). Imnaha flows, which were the earliest CRFB flows, filled the canyons that predate the Miocene volcano eruptions and are now exposed on granite near the tops of the Wallowa and Seven Devils mountains as a result of uplift throughout the Tertiary.

The Grande Ronde basalt from the Early to Middle Miocene (16.5-15.6 mya) covers the older Imnaha basalt and is the most extensive geologic formation within the Columbia Plateau. Approximately 80-85% of the total volume of the CRFB erupted in Grand Ronde basalts in less than one million years (Tolan et al. 1989, Hales et al. 2005). Most Grande Ronde flows were fed by zones of concentrated dikes within the Chief Joseph Dike Swarm that extended from the Pasco Basin, Washington to Western Idaho (Hooper 1997). These basalt flows covered long distances (200 to 400 miles) likely requiring very high eruption rates (Hooper 1997). Grande Ronde basalt extends north and northwest of the unconsolidated sediments in the Glenwood Valley (Vaccaro 1999).

Following a short lull in volcanic activity, eruptions of Wanapum basalts occurred 15-14.5 mya. The Wanapum basalt flows are characterized by high iron, titanium, and phosphorus, and depleted in silica (Hooper 1997). Most of the Wanapum basalt flows erupted from the western margin of the Chief Joseph Dike Swarm. Wanapum basalt from the Middle Miocene overlies the Grande Ronde basalt to the south of Glenwood Valley (Vaccaro 1999) and is classified as an andesite tholeiite (Hunting et al. 1961, Ludington et al. 2007) (Fig. 3). Eruption rates declined between 14.5 and 6 mya when Saddle Mountain basalt flows occurred (Hooper 1997). Mostly small flows, these basalts filled valleys and canyons in the older basalts that were created by tectonic deformation and river erosion (Hooper 1997). Saddle Mountain basalt flows are located near the center of the Columbia Plateau and do not extend west to CLNWR.

The western and southern portions of the Columbia Plateau warped and folded late in the eruptive cycle, creating several anticlines, synclines, and uplift areas (Vaccaro 1999). Generally trending east to west, basalt lava flows buckled steeply. Yakima Ridge, Saddle Mountains, and the long ridges that extend east from the Cascades into the Columbia

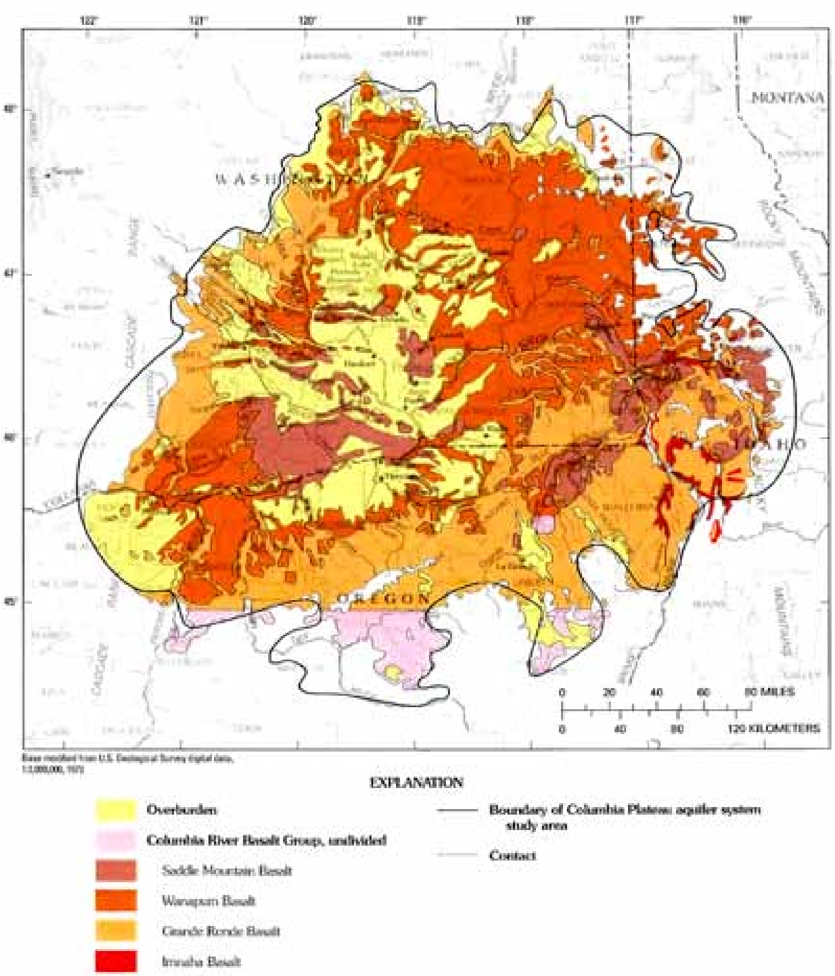

Figure 2. Surficial geology of the Columbia Plateau Regional Aquifer System. (From Vaccaro, 1999).

Plateau are anticlines formed in the CRFB dating back to 10 mya due to the northward movement of the west coast that buckled the rocks (Alt and Hyndman 1984). The Horse Heaven Hills occur along an anticline in northern Klickitat County (Vaccaro 1999). The NE-SW trending ridge extending along the south side of Camas Prairie is the western part of an anticline (Brown 1979). Two strike-slip faults occur across the Klickitat River.

Numerous occurrences of pillow-palagonite complexes in the CRFB suggest that many lakes and rivers occurred on the Columbia Plateau during volcanic eruptions (Hooper 1997). Red streaks, apparent on many canyon walls and road cuts, are old soils sandwiched between lava flows. White sediments represent old lake beds formed by large lava flows that blocked streams and impounded lakes and marshes that accumulated sediment (Alt and Hyndman 1984). Lake deposits between lava flows, or Latah formations, are mostly Kaolinite clay eroded from laterite soils comprised of red iron oxide, aluminum oxide, and clay (Alt and Hyndman 1984).

The sedimentary deposits indicate a warm and wet climate during the Miocene when the CRFB underneath the Columbia Plateau were active (Alt and Hyndman 1984). Leaf impressions preserved in volcanic rhyolite ash deposits in some Latah formations and petrified wood where lava buried water-soaked logs are from species of trees that thrive in the Caribbean region today. Following the warm tropical environment of the Miocene, a dry period occurred during the Pliocene when extensive gravel was deposited because streams did not have enough flow to carry sediments to the ocean and sparser vegetation did not protect soils from erosion (Alt and Hyndman 1984).

Lahars, or volcanic mud/debris flows, from Mount Adams were common during the Pleistocene and varied in texture depending on the event. CLNWR is located within a Holocene and late Pleistocene lahar from Mount Adams (Strachan and Pilson 2013). This alluvium is an unconsolidated sedimentary deposit consisting of gravels, sands, and silts of glacial and/or glaciofluvial origin (Brown 1979). Most of the basalt within the approved boundary of CLNWR is overlain by Holocene alluvium (Hunting et al. 1961, Ludington et al. 2007) (Fig. 3). This unconsolidated alluvium covering most of the Glenwood Valley includes "water-transported mud, sand, gravel, and coarser debris deposited in or adjacent to present day streams, lakes, and swamps" (Hildreth and Fierstein 1995). In summary, surficial geology includes alluvium surrounded by CRFB to the south and Quaternary basalt and andesite lava flows from Mount Adams to the west and north (Hunting et al. 1961, Hildreth and Fierstein 1995, Ludington et al. 2007).

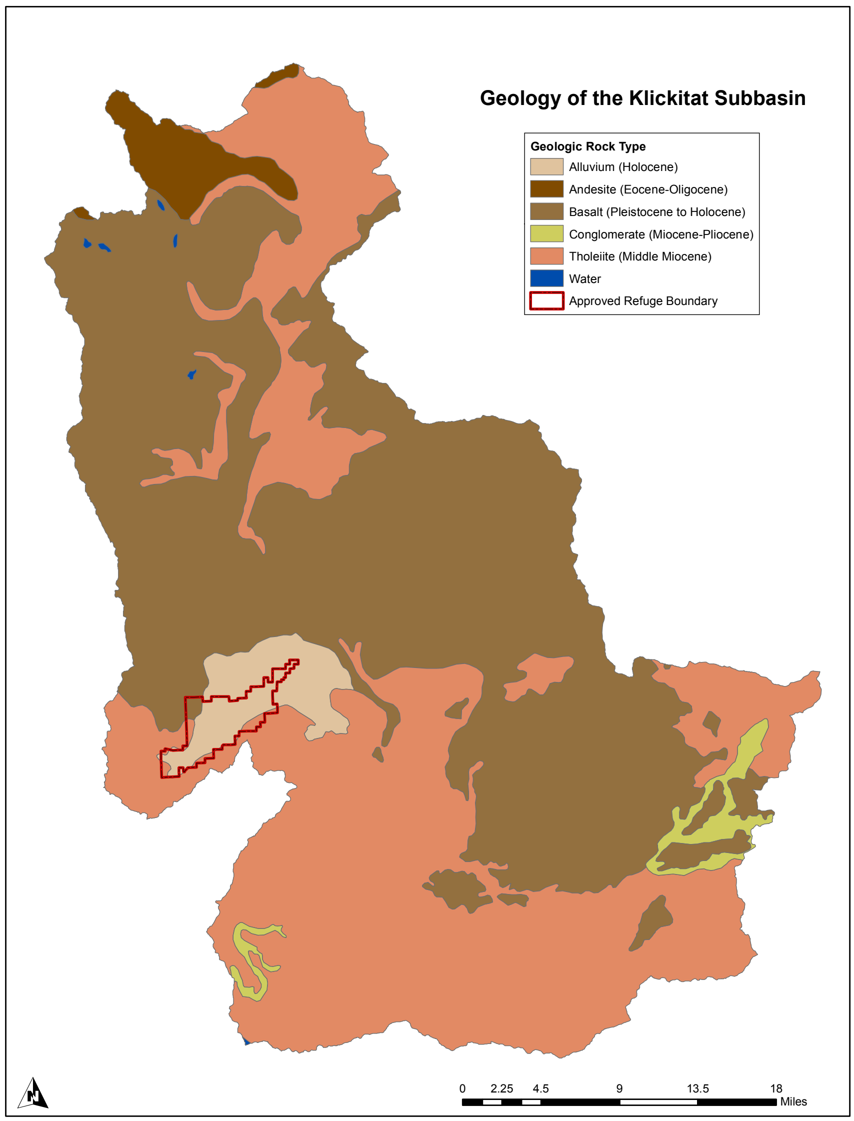

Figure 3. Geologic map of the Klickitat Subbasin and Conboy Lake National Wildlife Refuge. (Data from Ludington et al.,2007; based on Hunting et al., 1961).

SOILS

Soil data available for CLNWR include the U.S. Department of Agriculture Natural Resources Conservation Service (NRCS) Yakima Nation Area soil survey obtained from the Bureau of Indian Affairs. Eighteen different soil classifications occur within the approved boundary (Fig. 4). Soils within the refuge are dominated by relatively flat silty clay loam and clay loam. Soils along the diagonal southern boundary and in the northeast region of the approved refuge boundary include loam, stony sandy loam, sandy loams, and stony loams.

Three soil types cover approximately 68% (7,475 acres) of the land within the approved boundary of the refuge; these are Grayland silty clay loam, Conboy clay loam, and Segidal sandy loam (Table 1, Fig. 4). Grayland silty clay loam and Conboy clay loam each cover approximately 25% of the approved refuge boundary. Both soil types are classified as poorly drained with slow (Grayland series) and moderately slow (Conboy series) permeability. The next largest soil type is Segidal sandy loam, which covers approximately 18% of the approved refuge area along the northern boundary. Segidal sandy loam is somewhat poorly drained with moderate permeability above a cemented horizon (29 to 50 inches below the surface) with slow permeability below it.

Mapped soil types from six soil series (Fanal, Guler, Kaiders, Kreft, Panak, and Underwood) cover between 1 and 10% of the approved refuge area. These are moderately well to well-drained soils with slopes ranging from 0-2% to 30-65% located near the edge of the approved refuge area. The remaining soil types each cover < 1%.

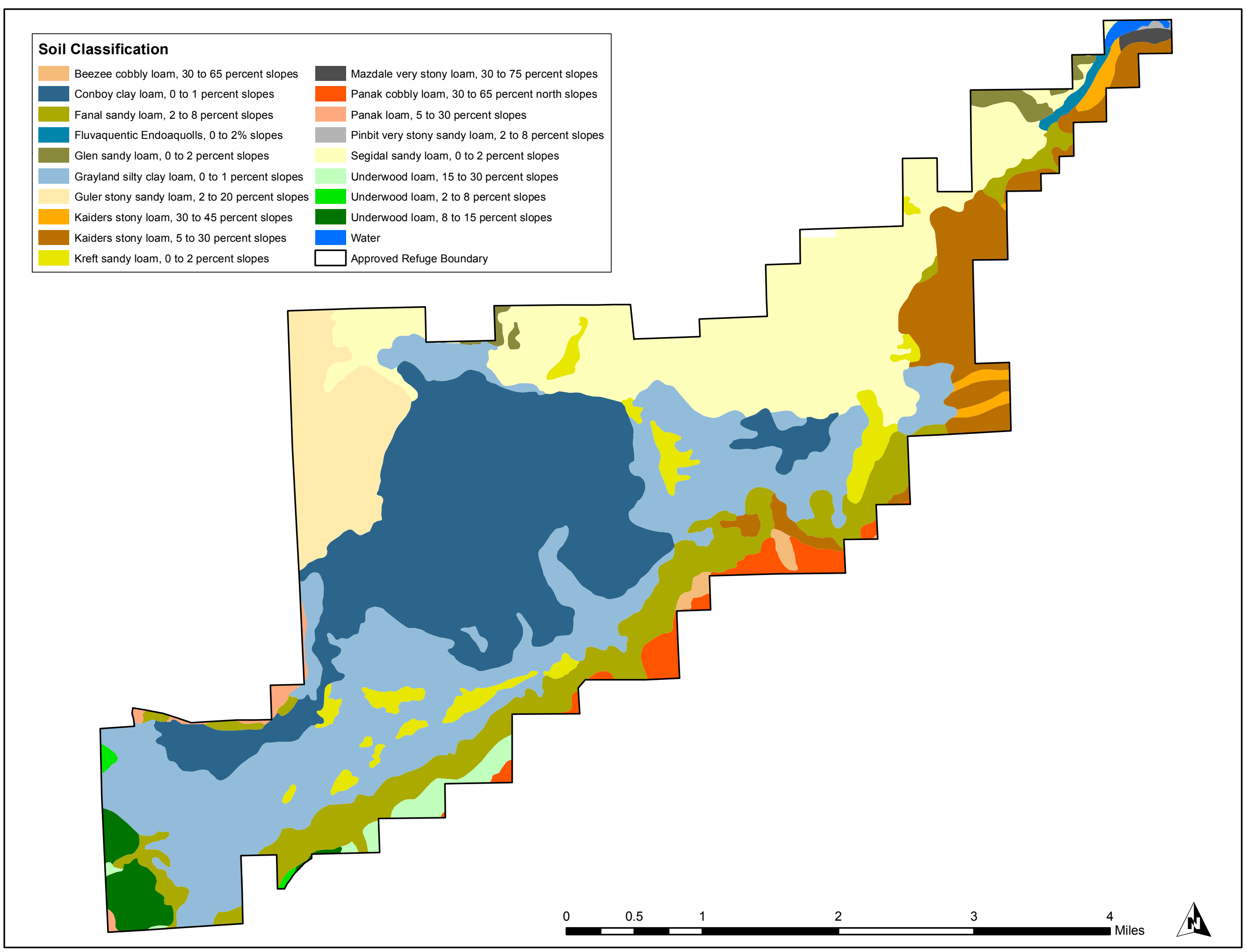

Figure 4. Soil types within the approved refuge boundary of Conboy Lake National Wildlife Refuge. (From Yakima Nation Area soil survey by NRCS; data provided by the Bureau of Indian Affairs).

TOPOGRAPHY

Detailed elevation data for CLNWR are limited. Aerial and ground surveys for topographic mapping at the refuge were completed during 1978-1980, and a 1-foot contour topographic map was completed during 1981 (USFWS refuge annual narratives). These data were recently located by USFWS and are more detailed than other available data (Fig. 5). Other data available include 45 point elevations surveyed in 1998 and the 10-meter National Elevation Dataset (Fig. 6) (Gesch et al. 2002, Gesch 2007). The Glenwood Valley is relatively flat compared to the surrounding landscape. Elevation in the Camas Prairie and Conboy Lake gradually rises from 1,811 feet at the lowest part of the valley to 1,831 feet where Bird and Frasier creeks enter CLNWR along its northern boundary (Fig. 6). A

Table 1. Characteristics of soil series within the approved refuge boundary of CLNWR. (Data summarized from NRCS official soil series descriptions, https://soilseries.sc.egov.usda.gov/osdname.asp).

Soil Type (Unit No.)	Acres[a]	Landform	Parent Material	Slope	Drainage Class	Permeability	Runoff	pH
Beezee cobbly loam	43.7	Canyon side slopes	Colluvium from basalt mixed with loess	30-65%	Well drained	Moderate	Medium to rapid	6.0
Conboy clay loam (1920)	2,643.8	Lake basins	Mixed alluvium from volcanic ash, diatomite, & basalt	0-1%	Poorly drained	Moderaly slow	Very slow	5.6
Fanal sandy loam (1923)	1,009.4	Toe slopes	Alluvium from basalt Colluvium from basalt	2-8%	Moderately well drained	Moderate	Slow to medium	6.0
Fluvaquentic Endoaquolls (1926)	33.0			0-2%				
Glen sandy loam (1924)	87.2	Low terraces	Alluvium from basalt & volcanic ash	0-2%	Well drained	Moderately rapid	Slow	6.0
Grayland silty clay loam (1921)	2,769.8	Lacustrine terraces	Lasuctrine sediments Alluvium from basalt & volcanic ash	0-1%	Poorly drained	Slow	Ponded to very slow	5.2
Guler stony sandy loam (1916)	671.9	Mountain footslopes	Volcanic ash Colluvium from basalt	2-20%	Well drained	Moderately rapid	Slow to medium	5.8
Kaiders stony loam[b] (1904, 1905)	723.0	Mountains Foothills	Colluvium from basalt Volcanic ash (minor) Loess (minor)	5-45%	Well drained	Moderate	Medium to rapid	6.6
Kreft sandy loam (1922)	347.1	Low terraces	Alluvium from basalt & volcanic ash	0-2%	Moderately well drained	Moderate	Slow	6.4
Mazdale very stony loam (1630)	23.8	North-facing canyon side slopes	Colluvium from basalt	30-75%	Well drained	Moderate	Medium to rapid	5.5
Panak loam (1933)	45.5	Mountain summts Mountain side slopes	Colluvium over residuum from basalt	5-30%	Well drained	Moderate	Medium to rapid	6.0
Panak cobbly loam[b] (1935)	187.7	Mountain summts Mountain side slopes	Colluvium over residuum from basalt	30-65%	Well drained	Moderate	Medium to rapid	6.0
Pinbit very stony sandy loam[b] (1927)	5.1	Terraces	Volcanic ash Alluvium from basalt	2-8%	Well drained	Moderate	Slow to medium	6.1
Segidal sandy loam (1925)	2,062.9	Lacustrine terraces	Alluvium	0-2%	Somewhat poorly drained	Moderate above cemented horizon and slow below	Very slow	5.9
Underwood loam (1929, 1930, 1931)	300.4	Mountain back slopes Mountain foot slopes Benches	Residuum Colluvium from basalt & andesite	2-30%	Well drained	Moderately slow	Medium to rapid	6.2
Water (W)	21.4							

[a]Acres within approved refuge acuisition boundary.

[b]Soil series description typical pedon is based a different soil type within the same series.

Figure 5. Elevation contours at Conboy Lake National Wildlife Refuge based on aerial photography and ground surveys during 1978-1980. (From USFWS Region 1 Engineering Division, S. Pilson, USFWS personal communication).

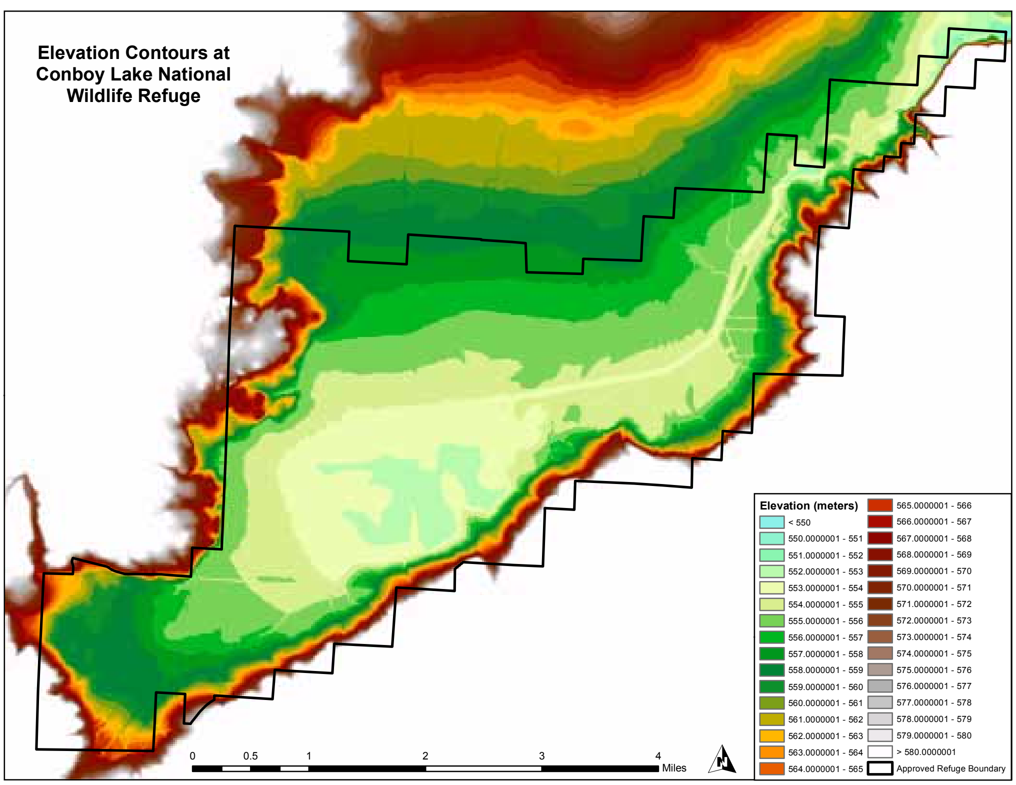

Figure 6. Elevation contours derived from 10-meter national elevation dataset at Conboy Lake National Wildlife Refuge (From Gesch et al. 2002, Gesch 2007).

low topographic rise occurred between the historical Camas Prairie and Conboy Lake (Strachan and Pilson 2013). A small outlet channel through a break in the topographic rise connected the Camas Prairie with Conboy Lake (Spray 1875) (see discussion in hydrology section below). Along the southeast refuge boundary, elevation steeply rises to over 2,297 feet in the hills surrounding Camas Prairie.

CLIMATE AND HYDROLOGY

Climate

Historical climate data from the Glenwood 2 Station 453184 is the closest to CLNWR, but only provides data back to 1958 and the station has been moved four times. Long-term climate data from the U.S. Historical Climatology Network (USHCN) (Menne et al. 2012) is available for the Goldendale Station 453222 (1895-2011), approximately 25 miles southeast of the refuge. Average annual precipitation at Glenwood, Washington from 1971-2000 (32.21 inches/year) is twice the average precipitation at Goldendale (16.47 inches/year) based on Parameter-elevation Regressions on Independent Slopes Model (PRISM) (Daly 2002, Daly et al. 2008). Because precipitation data from Goldendale does not accurately represent conditions at CLNWR, data from the PRISM Climate Group (2012) are used to characterize the historical precipitation patterns. Average annual high and low temperatures are similar between stations, varying by 2 degrees Fahrenheit.

Long-term average annual precipitation for the water year (Oct. 1-Sept. 30) for Glenwood is 32.9 inches/year and ranges from 46 to 152% of the average (PRISM Climate Group 2012) (Fig. 7). Most of the precipitation occurs during the winter months, with an average >5 inches/month during November, December, and January. Precipitation gradually declines through the spring reaching <1 inch/month during June, July, August, and September (Western Regional Climate Center 2014) (Fig. 8).

Average daily high temperatures range from about 80 degrees Fahrenheit during the summer to 35-40 degrees Fahrenheit during the winter. Average daily low temperatures range from 45 degrees Fahrenheit during the summer to 20 degrees Fahrenheit during the winter (Fig. 9). Hot, dry summers result in relatively high evaporation rates. Based on evapotranspiration estimates for restored and incised riparian meadows (Hammersmark et al.

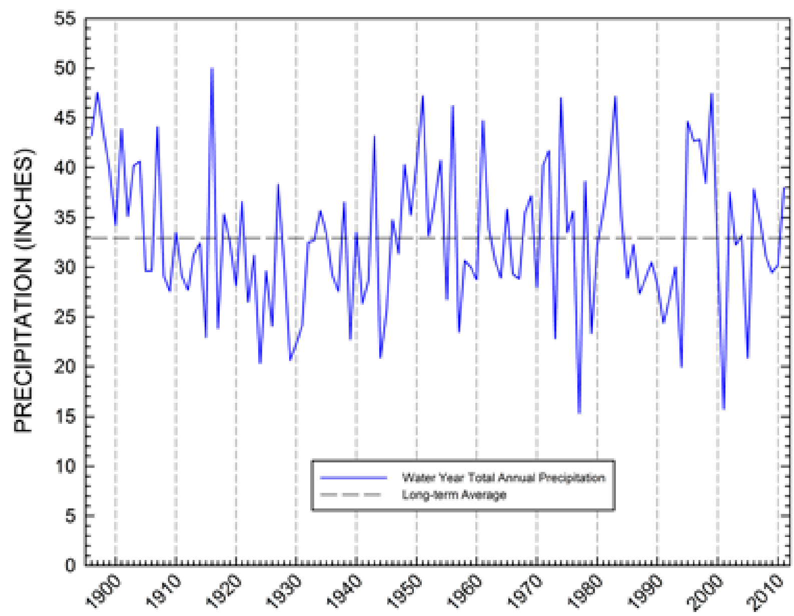

Figure 7. Water year (Oct. 1 – Sept. 30) total annual precipitation at Glenwood, Washington from 1896 to 2011. (Data compiled from PRISM Climate Group 2012).

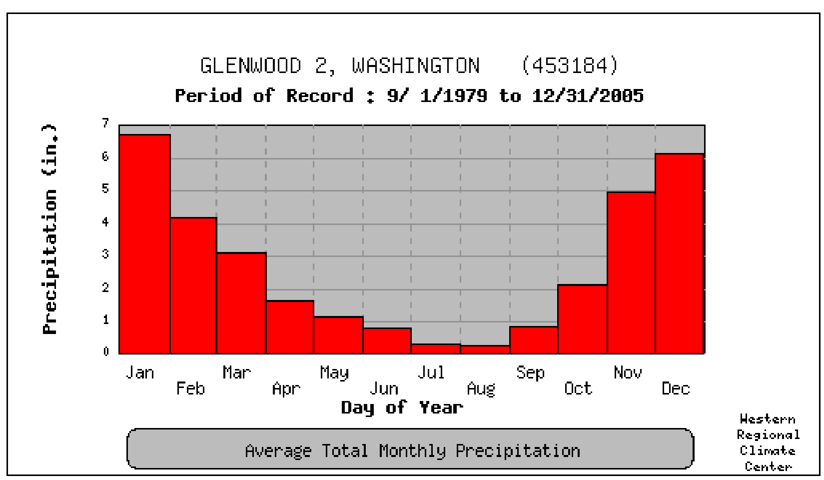

Figure 8. Average total monthly precipitation at Glenwood, Washington from 1979 to 2012. (From Western Regional Climate Center 2014).

2008), historical evapotranspiration rates during the summer may have been 25-50% higher than current estimates due to hydrologic modifications.

The Surprise Lakes SNOTEL station (elevation 4,290 feet), located on the southwest slope of Mount Adams (Skamania County, Washington), has been in operation since October 1979 (NRCS 2014). Snow water equivalent (SWE) is the amount of water contained within the snowpack based on the density of the snow. The SWE at Surprise Lakes usually peaks during mid-April. For the period of record, annual peak SWE ranged from 10.5 (April 2005) to 86.0 inches (April 1999) (Fig. 10).

The Palmer Drought Hydrological Index (PDHI) is a long-term cumulative index used to quantify the hydrological impacts of drought (e.g., groundwater levels, etc.) that generally take longer to develop and recover from. During the early 20th century, wet/dry cycles occurred at relatively long intervals with a 25-year wet period from 1896 to 1921 and a 17-year wet period from 1946 to 1962. These wet periods were separated by a 24-year drought period from 1922 to 1945. Since 1963, relatively short (5-10 years) periods of wet and dry conditions have occurred in the region (Fig. 11) (NOAA 2014).

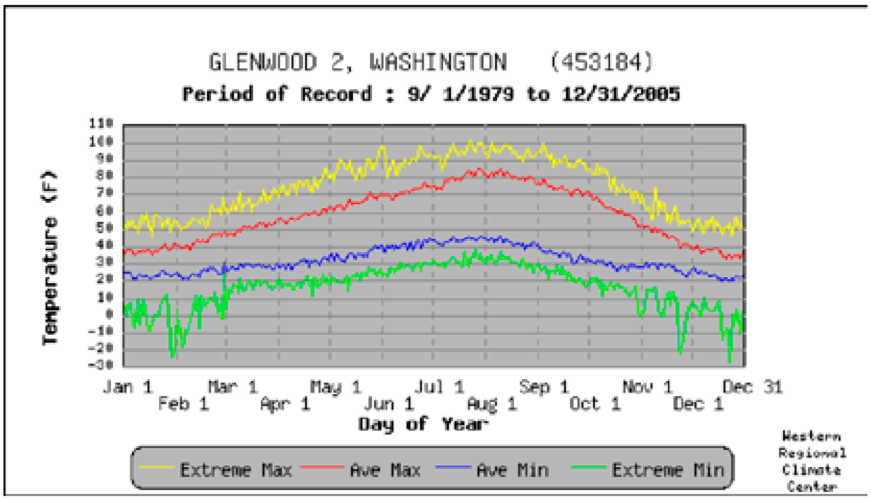

Figure 9. Daily temperature statistics for Glenwood, Washington from 1979 to 2005. (From Western Regional Climate Center 2014).

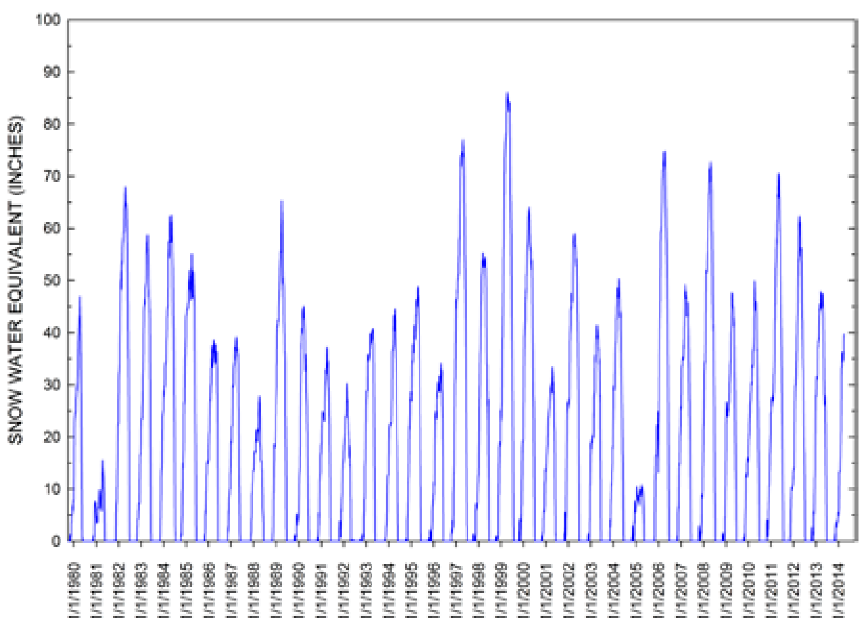

Figure 10. Daily snow water equivalent at Surprise Lakes, Washington (SNOTEL site 804) on the southwest slope of Mount Adams from 1 October 1979 to 4 April 2014. (Data compiled from NRCS 2014).

Reconstruction of paleoclimate conditions in the Western United States indicates wet and dry periods have fluctuated on interannual, decadal, multi-decadal, and centennial-scale time periods throughout the Holocene (e.g., Cook et al. 2004, Pederson et al. 2006, Cook et al. 2007). The Western United States experienced long periods of intense drought during warmer and drier conditions from 900 to 1300 (Medieval Warm Period) followed by wetter and cooler conditions during the Little Ice Age (1400-1700), 1829, and 1915 (Cook et al. 2004).

Climatic conditions in south-central Washington during the early 19th century include periods of above-average wet conditions during 1805-1806 and 1818-1820 when the interior Western United States was experiencing severe droughts (Cook et al. 2007). The subsequent widespread wet period of the 1820s in the Western U.S. was one of the four wettest epochs in the past 1,200 years (Cook et al. 2004). During 1867-1869, south-central Washington experienced drought conditions followed by above average wet conditions during 1876-1878.

From the late 1880s to 1896, a severe drought occurred across the Western United States and Great Plains (Cooke et al. 2007). Wet conditions returned during the early 1900s with 1915 as the mid-point in another of the four wettest epochs during the past 1,200 years (Cook et al. 2004).

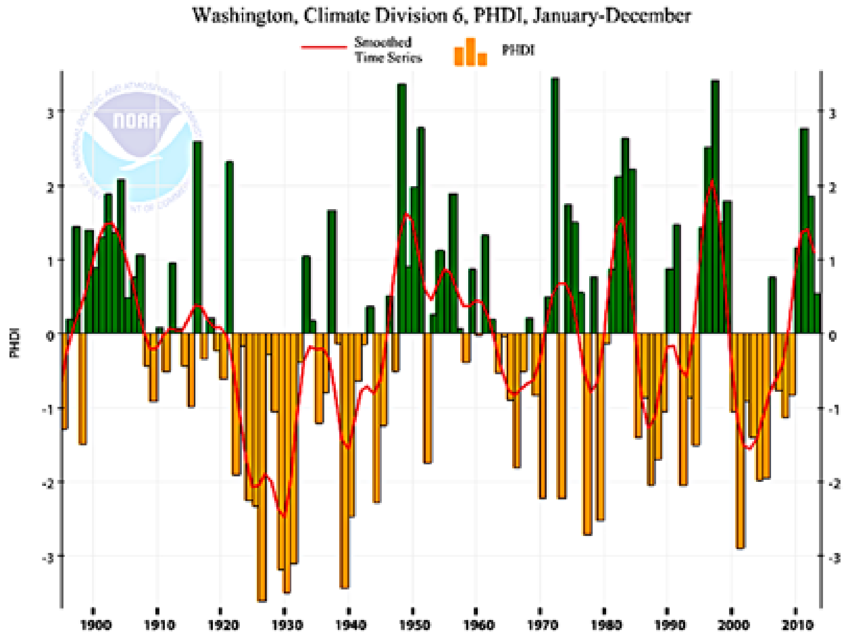

Figure 11. Annual Palmer Drought Hydrologic Index (PDHI) for the East Slope Cascades, Washington (Climate Division 6) from 1896 to 2013. (From NOAA 2014).

Recent climate change patterns for the Upper Columbia River Basin during the 20th century summarized by McWethy et al. (2010) include: 1) increased temperatures in most areas of 0.9 to 3.6 degrees Fahrenheit; 2) increasing night time minimum temperatures; 3) variable trends in precipitation; 4) significant declines in snowpack; and 5) earlier snowmelt and peak runoff and associated decreases in summer stream flows. During the 20th century, annual average temperatures in the Maritime, Central, and Rocky Mountain climatic zones of the Pacific Northwest increased by 1.2 to 1.6 degrees Fahrenheit (Mote 2003b). The largest upward trends in all climatic zones occurred during winter (January-March). For the central Pacific Northwest (Washington and Oregon east of the crest of the Cascade Mountains) temperatures increased 4.3 degrees Fahrenheit during winter, but the trend was not statistically significant. Similar to regional patterns, average and maximum annual temperatures at Hood River, Oregon (approximately 24 miles southwest of Glenwood, Washington) have also increased (Strachan and Pilson 2013). Increases in air temperature at Hood River, Oregon were highest during the winter, summer, and fall; whereas spring temperatures decreased (Strachan and Pilson 2013). Precipitation has increased 13 to 38% across the Pacific Northwest (Mote 2003b).

The trend in decreasing SWE of 1 April snowpack throughout the Western United States is primarily related to increases in temperature and a decrease in the amount of precipitation falling as snow, as indicated by summaries of seasonal climate at nearby stations (Hamlet et al. 2005, Mote et al. 2005, Knowles et al. 2006, Mote 2006). In the Cascade Mountains, 1 April SWE was strongly correlated to temperature below 4,900 feet in Washington and below 5,900 feet in Oregon (Mote 2003a). Alpine glaciers on Mount Adams have decreased in aerial extent by 49% from 1904 to 2006 likely driven by increases in temperature (Sitts et al. 2010). Earlier snowmelt was also related to increased evapotranspiration and earlier soil recharge indicated by increased soil moisture during spring (Hamlet et al. 2007).

Surface Water

Precipitation and glaciers on Mount Adams, timing of snowmelt throughout the Klickitat Subbasin, groundwater discharge, and local precipitation in the Glenwood Valley influenced stream flow entering the historical Conboy Lake and associated Camas Prairie wetlands. CLNWR is within the Middle Klickitat Watershed, located at the lower elevation of the winter snow zone where snow melts earlier in the season compared to the higher elevation mountainous area of the Upper Klickitat Watershed (Strachan and Pilson 2013). Within the Middle Klickitat Watershed, portions of four subwatersheds (Chapman Creek, Draper Springs, Frasier Creek, and Outlet Creek) are located within the approved boundary of the refuge (Fig. 12). Bird Creek and its tributaries drain an area of over 28 square miles; Holmes and Chapman creeks have a combined watershed of 27 square miles (Strachan and Pilson 2013).

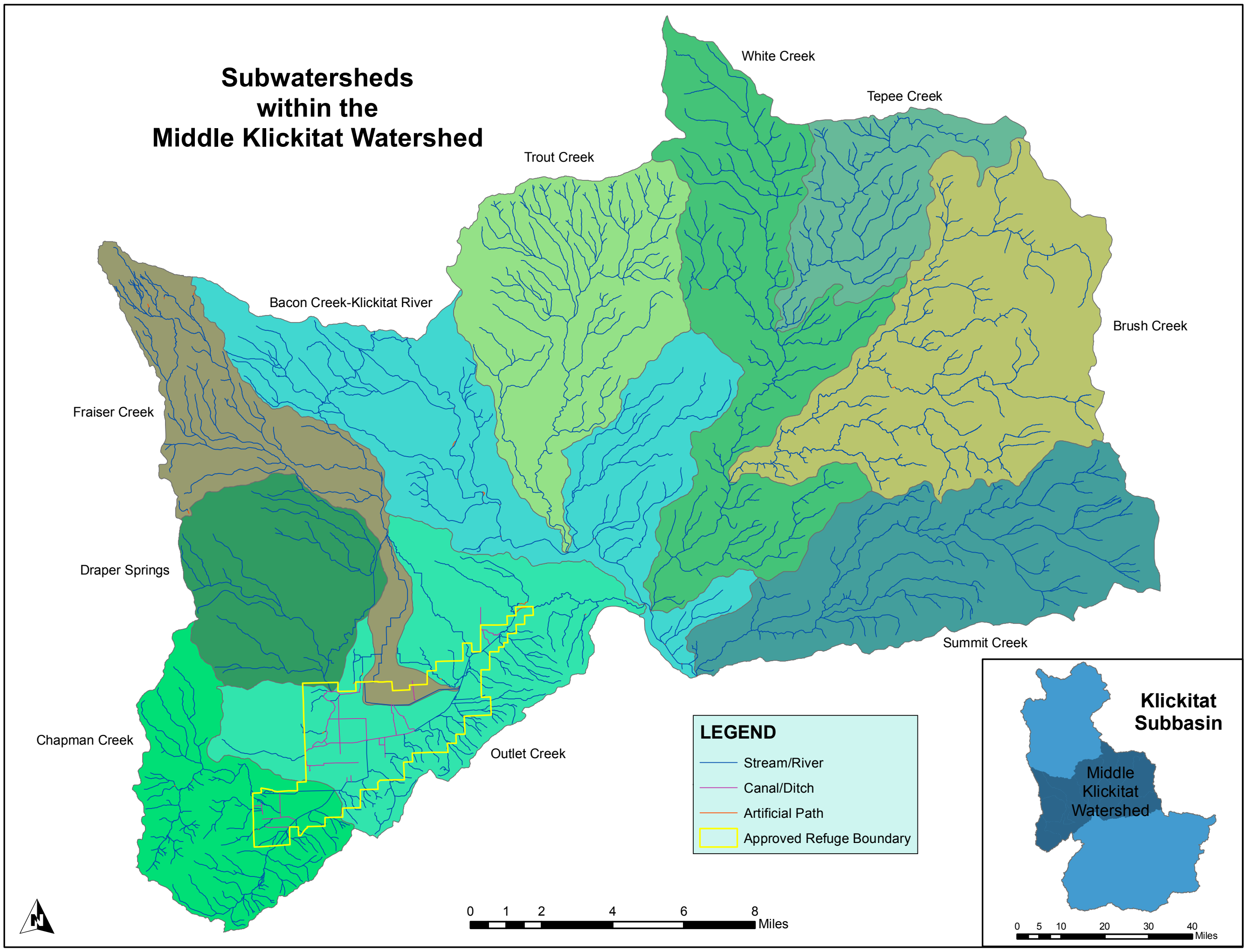

Figure 12. Subwatersheds and flowlines within the Middle Klickitat Watershed. (Data from National Hydrography Dataset, http://nhd.usgs.gov/).

Glacial outburst floods resulted in dynamic changes in stream reaches. Rusk Glacier on the east side of Mount Adams provides water to Big Muddy. During 1988 two glacial outburst floods from the Rusk Glacier cut a new channel down the mountain (USFWS 1988 refuge annual narrative). Within the Glenwood Valley, stream gradients were relatively shallow. Stream migration rates through wet meadows are relatively small compared to stream migration rates through upland meadows (Micheli & Kirchner 2002). Early accounts (The Enterprise 1911) describe: "that because of the nearly flat topography of the valley, some of the creeks did not have a defined channel but rather spread over the whole area. From the south, Chapman Creek flows, from the east range the Holmes, and from the north, the Bird and Frasier creeks enter, the latter fed by glacial springs and the snows of Mount Adams. The water from these streams overspread the land for about ten out of twelve months in the year." During 1875, a short, unlabeled creek (possibly Frasier Creek) was mapped northwest of Outlet Creek in Sections 14 and 15 of Township 6 North, Range 12 East, but no defined channel was shown into Conboy Lake or Outlet Creek (Fig. 13) (Spray 1875).

Historically, sinuous channels of Bird and several unlabeled creeks flowed into the Glenwood Valley (Fig. 13 and Fig. 14). A small stream, 100 links (66 feet) wide, flowed east through a low spot in a topographic rise between Camas Prairie and Conboy Lake (Fig. 13) (Spray 1875). Surface water from Camas Prairie flowed into Conboy Lake through this "Upper Outlet" (Spray 1875), which drained northeast through Outlet Creek to the Klickitat River.

Limited stream flow data for the creeks entering the refuge are available, but data from

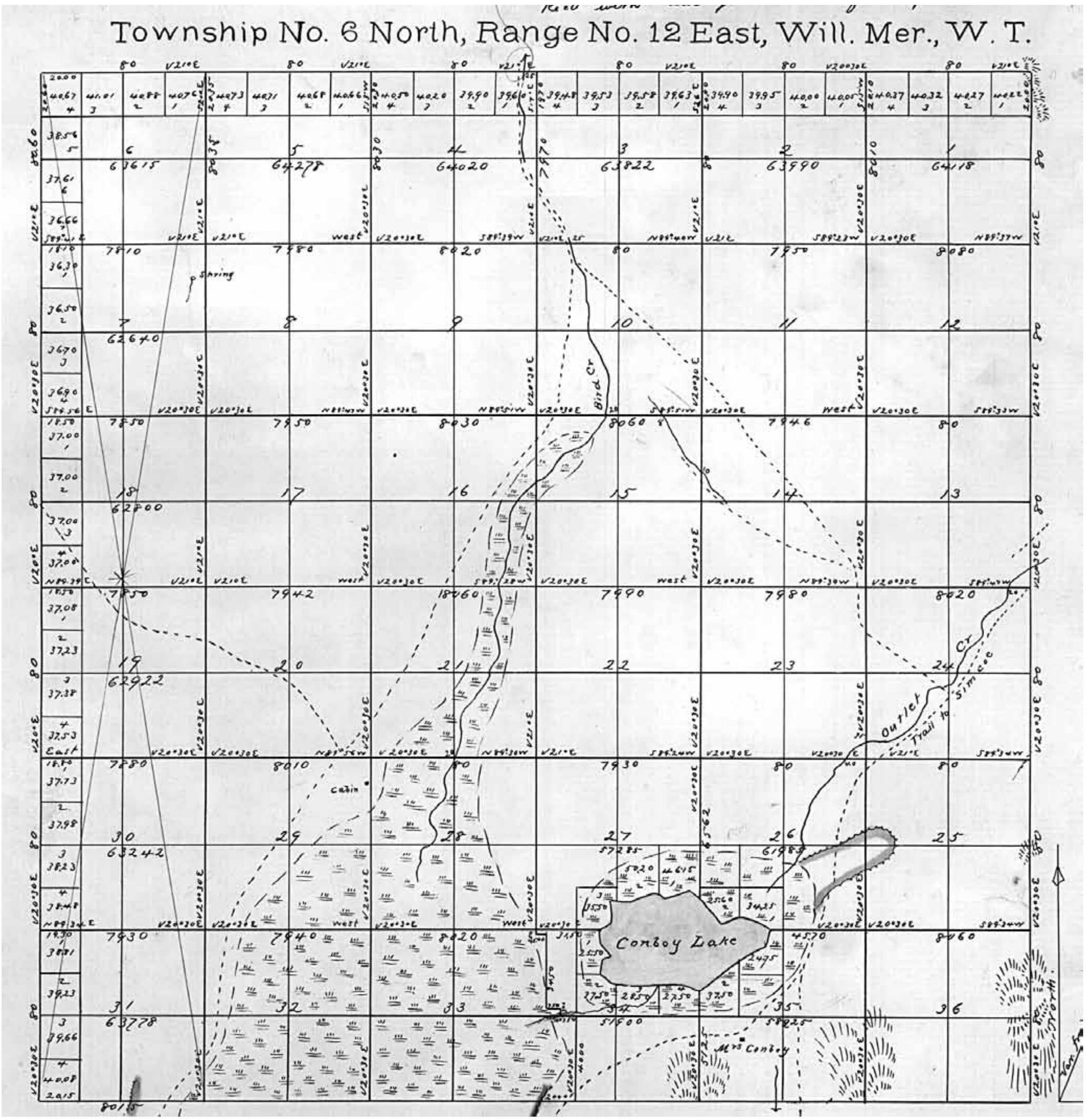

Figure 13. General Land Office survey map for Township 6 North, Range 12 East based on field surveys from 22 October to 7 November 1875 (Spray 1875).

the Klickitat River are used to represent annual and seasonal variability of surface water inputs at CLNWR. Average monthly discharge at Klickitat River near Glenwood, Washington (USGS station number 14110000, drainage = 360 square miles), peaks during May (1,849 cubic feet per second [cfs]) and the majority of the flow occurs during April, May, and June (Fig. 15) (USGS 2014). Annual peak flows ranged from 835 to 9,870 cfs during 1910-1979 (Fig. 16) and generally occurred during the late spring, but could occur anytime from November to June. Historically, a peak discharge of >3,000 cfs occurred in about 50% of all years (Table 2). Annual flood events of >6,000 cfs were rare near Glenwood, but occurred 6 times during the 70-year period of record. Similar variability in peak stream flow is observed

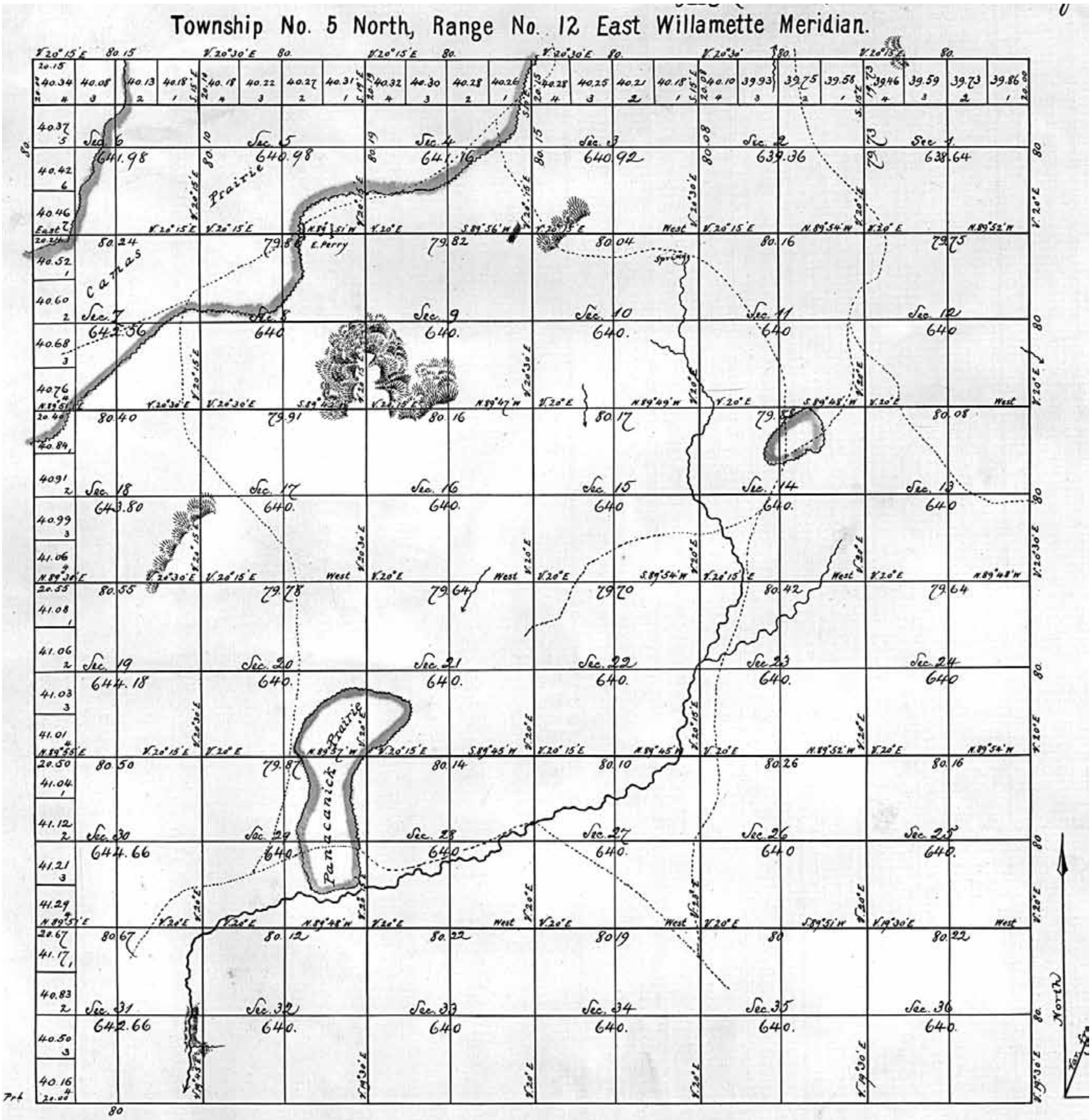

Figure 14. General Land Office survey map of Township 5 North, Range 12 East based on field surveys from 10 October to 4 November 1873 (Spray 1873b).

at the Klickitat River above West Fork (USGS station number 14107000, drainage = 151 square miles), but at lower flows (Fig. 16). Flood events in the Lower Klickitat Watershed (e.g., Klickitat River near Pitt, Washington) generally occurred during a warm period in the winter as a result of heavy rains and melting snow (Cline 1976). Peak stream flow at Medley Canyon Creek (USGS station number 14110700; drainage = 1.26 square miles), which enters the refuge from the south, is only available from 1970-1976. Annual peak stream flow during that time period ranged from 6.2 to 84 cfs (Fig. 17).

Annual seven-day low flow, a good indicator of minimum base flow, also varies considerably among stations and years. The mean seven-day average low flow for Klickitat River near Glenwood was 359 cfs, ranging from 245 to 488 cfs during 1909-1971 (Cline 1976). The mean seven-day average low flow occurred in approximately 50% of all years from 1909-1971 (Table 3). Cline (1976) estimated that the seven-day average low flow of 76 cfs for Outlet Creek (drainage = 130 square miles) occurred in 50% of all years.

Comparing peak stream flow and snowmelt at Surprise Lakes, SNOTEL, Strachan and Pilson (2013) estimated the peak hydroperiod for the historical Camas Prairie and Conboy Lake occurred during May or June. The annual maximum extent of historical surface water flooding generally ranged from 3,000 to 6,000 acres. As precipitation and snowmelt declined, water levels receded throughout the summer, lost to evapotranspiration, infiltration, subsurface flow, and discharge of the historical Camas Prairie and Conboy Lake through Outlet Creek. Groundwater discharge through springs, basal flux of the shallow groundwater, and/or hillslope groundwater flux maintained temporally variable areas of permanent or semi-permanent water through the summer. The annual minimum extent of surface water during the summer was estimated to range between 400 and 1,000 acres (USFWS 1975 refuge annual narrative). Fall rains had a significant impact on historical wetlands, generally refilling seasonal wetland during October or November. For example, heavy rains during late December 1972 flooded 4,000 acres of the historical Conboy Lake (USFWS 1972 refuge annual narrative).

Brown (1979) calculated water budgets for several locations in Klickitat County. High elevation areas in the western part of the county (e.g., Appleton, White Salmon, and Mount Adams Ranger Station) tend to have water surpluses during the winter. Evapotranspiration exceeds precipitation during June, July, and August in all locations. Summer water deficits were highest in the eastern part of Klickitat County as a result of decreased precipitation compared to western Klickitat County.

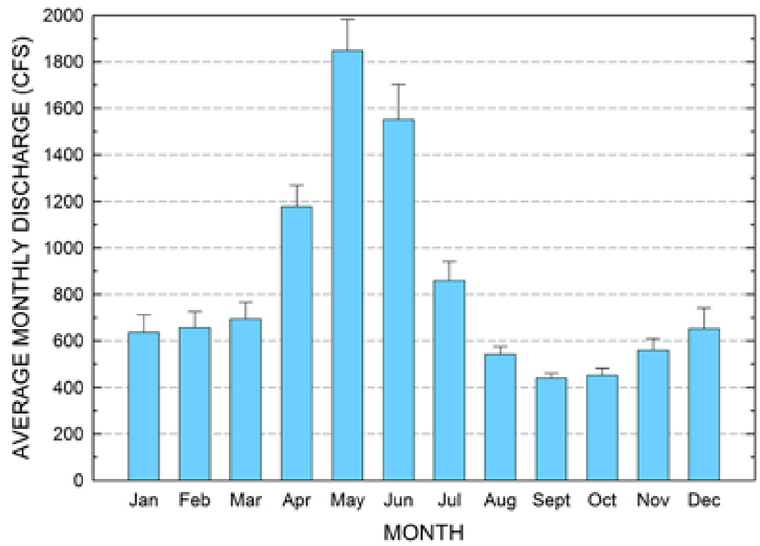

Figure 15. Mean average monthly discharge ± 95% confidence interval at Klickitat River near Glenwood, Washington (USGS station number 14110000) from 1909 to 1971. (Data compiled from USGS 2014).

Groundwater

The geologic formations of the Columbia Plateau and their hydrologic character are a primary factor controlling the distribution and availability of groundwater in the Columbia Plateau Regional Aquifer System (CPRAS) (Vaccaro 1999). The CPRAS of Southeastern Washington, Northeastern Oregon, and Western Idaho underlies the 70,000 square mile Columbia Plateau and contains four structural units: 1) Yakima Fold Belt, 2) Palouse Slope; 3) Blue Mountains; and 4) Clearwater Embayment (Snyder and Haynes 2010). CLNWR is located on the western edge of the Yakima Fold Belt structural region, where the geologic complexity of folds and faults affect groundwater movement (Snyder and Haynes 2010).

Table 2. Magnitude and probability of annual high flow for the Klickitat River at three gauging stations for the available periods of record (From Cline 1976).

River Location and Station Number	Annual peak discharge (cubic feet per second) for indicated recurrence interval, in years and exceedance probability , in percent					
	2 50%	5 20%	10 10%	25 4%	50 2%	100 1%
Klickitat River above West Fork Station No. 14107000	1,850	2,420	2,830	3,370	3,790	4,230
Klickitat River near Glenwood Station No. 14110000	3,140	4,330	5,180	6,300	7,180	8,100
Klickitat River near Pitt Station No. 14113000	8,200	14,700	20,400	29,300	37,300	46,600

Table 3. Annual seven-day low flow at stream sites in the Klickitat River Basin, based on climate year, April 1-March 31. From Cline (1976).

River/Creek Location	7-day low flow (cubic feet per second) for indicated recurrence interval, in years and exceedance probability , in percent					
	2	5	10	25	50	100
	50%	20%	10%	4%	2%	1%
Klickitat River above West Fork[a] Station No. 14107000	86	73	68	64	61	59
Klickitat River near Glenwood[b] Station No. 14110000	358	314	292	274	256	243
Trout Creek[c] NE 1/4 Sec. 5, T6N, R13E	3.8	3.3	3			
Outlet Creek[d] NW1/4 Sec. 14, T6N, R13E	76	68	63			

[a]Excludes low flows caused by severe freeze-up during Dec 1944 and Jan-Feb 1957.

[b]Includes the effect in some years of diversions to Hellroaring Ditch.

[c]Estimated based on correlation of 1 year of data with data from long-term gauging stations.

[d]Estimated based on correlation of 2 years of data with data from long-term gauging stations.

The CPRAS includes aquifers in the CRFB and basin fill sediments. It has an estimated predevelopment (1850s) total annual recharge of 6,566 cfs (4,750,000 acre-feet or 2.72 inches/year) (Vaccaro 1999). The aquifer is recharged by 1) infiltration of precipitation and snowmelt, 2) leakage from rivers, lakes and reservoirs, and 3) following European settlement, infiltration of applied irrigation water (Vaccaro 1999). Recharge is spatially variable, dependent primarily on precipitation and infiltration of irrigation returns. Other estimates of precipitation contribution to aquifer recharge are as high as 4.6 inches/year (Kahle et al. 2011). Discharge from the aquifer prior to ground-water pumping was primarily to surface-water features, springs, and seeps (Vaccaro 1999).

Generalized hydrogeologic units (from oldest to youngest) in the vicinity of CLNWR include the pre-basalt "basement" confining layer, Grande Ronde and Wanapum basalt units (including intercalated sediment), the semi-confining or locally confining Wanapum-Grand Ronde interbed, and the overburden unit of sedimentary deposits. Hydraulic characteristics of the hydro-geologic units in the CPRAS in the vicinity of CLNWR are summarized by Vacarro (1999). Hansen et al. (1994) estimated water budgets for the CPRAS and hydrogeologic layers within the CPRAS.

Wide ranges in lateral and vertical hydraulic conductivity within the basalt units reflect the heterogeneous nature of basalt. The water-bearing capacity of basalt and interflow zones can vary spatially over relatively short distances due to composition of intercalated sediments, filling of basalt pore spaces with clay and/or other minerals, faults, and folds. The central part of individual basalt flows tend to be dense and compact with low permeability. In contrast, the top of most flows are less dense as a result of gases rising to the surface as the lava cooled and therefore have high horizontal permeability (Brown 1979). Folds and faults disrupt the continuity of permeable zones and often act as barriers or zones for vertical migration of groundwater (Brown 1979).

General groundwater flow in the Wanapum and Grande Ronde hydrogeologic units are similar, with overall flow trending radially from the margins of the unit toward the center of the CPRAS or toward the Columbia River (Snyder and Haynes 2010). The general direction of groundwater flow in the Grande Ronde basalt east of the refuge is from the north boundary of Klickitat County southwest to the Columbia River. In Wanapum basalts within the Yakima Fold Belt groundwater generally flows southeastward along the axes of valleys toward the Yakima or Columbia rivers (Snyder and Haynes 2010).

Groundwater recharge and flow paths in the Cascade Mountains are controlled by the geographic extent of lava flows, and topographically defined watersheds may not coincide with aquifer boundaries (Jefferson et al. 2006). Older lava flows, buried by more recent flows often result in hidden groundwater flow paths (e.g., Join et al. 2005). Depths to water and yield of water-bearing zones vary considerably within the Upper Klickitat River Watershed. Assuming no net change in groundwater storage, groundwater recharge in the Upper Klickitat River Watershed is estimated at 550,000 acre-feet/year, primarily occurring on the slopes of Mount Adams (Cline 1976). Within the Klickitat Subbasin, groundwater flow is impeded by faults and anticlines in the Little Klickitat and Swale Creek Subwatersheds (Watershed Professionals Network and Aspect Consulting 2005). Geologic complexity of the Yakima

Fold Belt structural region contributes to compartmentalization of groundwater flow within the region (Snyder and Haynes 2010).

Groundwater in the Quaternary volcanics under the Camas Prairie region flows to the northeast, discharging to springs and streams. Numerous springs are located in the hills surrounding Camas Prairie, along the western boundary of Camas Prairie, and along the northwestern portion of the refuge (Brown 1979, USFWS 2005). Groundwater discharge to the Klickitat River from the Camas Prairie-Glenwood areas likely averages about 150 cfs, but could be much higher (Cline 1976). Water level fluctuations in the basalt aquifer under the Camas Prairie fluctuate more than in the shallow alluvial aquifer, with the highest levels occurring during the late summer (Cline 1976). Saturated zones in the basalt occur above the main groundwater body and water levels in these perched basalt aquifer fluctuate less than in the lower main groundwater basalt aquifer (Cline 1976).

Sedimentary deposits are present in most valleys on the Columbia Plateau and they contain a shallow alluvial aquifer when saturated. Groundwater in unconsolidated sedimentary deposits is generally at or near the surface. These sediments are more extensive at Camas Prairie than in other areas of Klickitat County, in part, due to alluvial sediments from Mount Adams, and are an important groundwater source (Cline 1976). Water levels in the shallow alluvial aquifer are strongly influenced by precipitation and snowmelt. For example, lower than average rainfall during 1976 and the first 10 months of 1977 caused groundwater levels to drop substantially; groundwater levels increased quickly when fall rains and snow recharged the shallow aquifer (USFWS 1977 refuge annual narrative). Water levels in the shallow alluvial aquifer are generally <20 feet below the land surface and during 1974 fluctuated <10 feet (Cline 1976). Water in the shallow alluvial aquifer is in direct hydraulic connection with the underlying basalt unit.

HISTORICAL FLORA AND FAUNA

Overview

Natural climatic variability and multidecadal changes in precipitation and temperatures were primary drivers of ecosystem process and vegetation community distribution in the Pacific Northwest and Columbia Basin (e.g., Whitlock 1992, McWethy et al. 2010). Beginning with its complex geologic formation

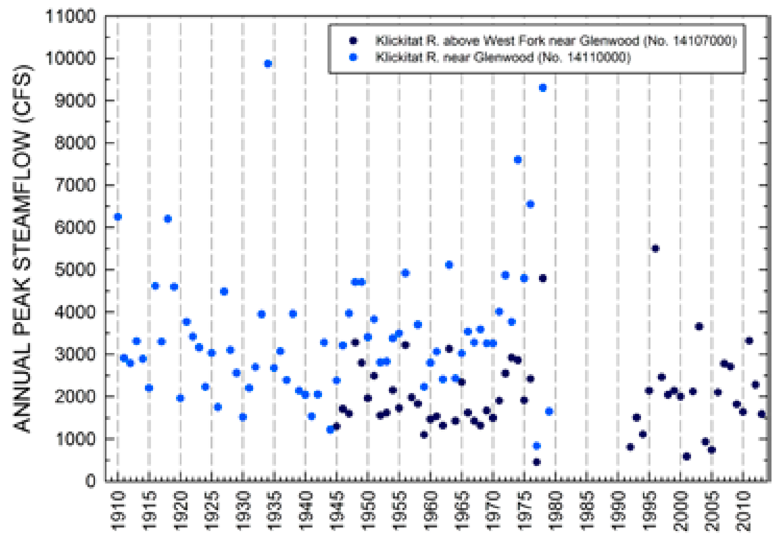

Figure 16. Annual peak streamflow at Klickitat River near Glenwood, Washington (USGS station number 14110000) from 1910 to 1979 and at Klickitat River above West Fork, near Glenwood, Washington from 1945 to 2013 (USGS station number 14107000). (From USGS 2014).

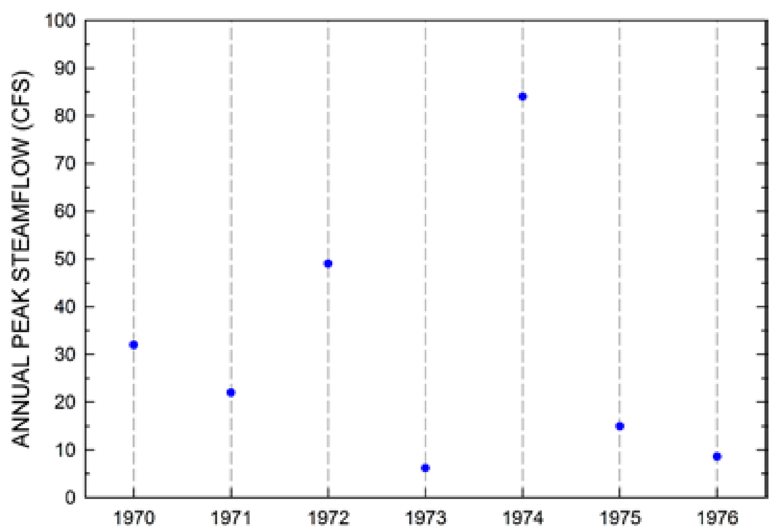

Figure 17. Annual peak streamflow at Medley Canyon Creek near Glenwood, Washington (USGS station number 14110700) from 1970 to 1976. (From USGS 2014).

and continuing through climatic variations during the Holocene, the Western Columbia Plateau ecosystem was a dynamic and heterogeneous landscape with diverse forms of volcanic rock outcrops, uplifted ridges and mountain ranges, and water-transported alluvium and lacustrine sediments. Stream drainages originating in the Cascade Mountains transported additional sediments eroded from Quaternary volcanic surfaces of the western portion of the Columbia Plateau.

Surface and groundwater inputs across heterogeneous soil substrates created a diverse mosaic of forested, grassland, riparian, and wetland habitats within the Glenwood Valley. Highly variable seasonal, annual, and multidecadal precipitation within the watershed resulted in variable recharge in the Upper Klickitat Watershed and variable extents of surface water flooding throughout the CLNWR area. Groundwater discharge and stream flow during wet years likely contributed perennial water sources to some areas. Observations noted on historical GLO surveys (e.g., Spray 1873a, Spray 1875) and recent hydrologic studies of other montane wet meadow areas (e.g., Loheide et al. 2009, Lowry et al. 2010) suggest that the heterogeneous spatial distribution and vertical profiles of soils and local geology create a complex interaction between ground and surface water movements. The spatial and temporal variation of water table depth and associated water stress or oxygen stress exerts a strong control on vegetation composition and spatial patterning (Lowry et al. 2011). Although not quantified prior to substantial anthropogenic surface water developments, these complex surface and groundwater interaction maintained the productive and diverse wetland habitats at the refuge.

Quantitative information on historical vegetation and animal communities is limited; however, GLO survey notes from the late-1800s, ethnobotanical information, and other early accounts provide qualitative descriptions of the composition and distribution of general habitat types. William Suksdorf collected plant specimens from the Glenwood Valley, Mount Adams, and other areas in Klickitat County as early as 1885. Resources in the Glenwood Valley provided staple resources for Native Americans and early European settlers. The earliest known written description of the Glenwood Valley is from 1853:

"Among these forests of the eastern slopes there are found at intervals prairies, which are superior in character of soil to those near the Great Plain. Such is the Tahk Plain, ten miles long and one to three miles wide, lying southeast of Mount Adams and at the bank of the Klickitat river, fifteen miles north of the Columbia, which has a lake in its centre, and is covered with luxuriant grasses" (Stevens 1860 as cited in Adams 1992).

Homesteaders' accounts of the Glenwood Valley describe Camas Prairie and its wild grass hay and alluvial soils as extremely fertile. William F. Jebe filed on a homestead in 1885 and described the area as "a tiny swale all covered with cottonwood trees and buck brush" with scattered crystal springs "where the range cattle, bears, deer and grouse filled themselves with the sparkling juice all summer long;" these springs were "surrounded by great tall stately pines and fir trees" (Jebe 1946).

Historical Vegetation Communities

Vegetation communities at CLNWR historically ranged from pine and fir-dominated forests on higher elevation mountainous terrain to riparian meadows along Bird Creek, seasonally flooded wetlands of the Camas Prairie, and nearly permanently-flooded wetlands within the historical Conboy Lake. Temporally variable disturbance regimes (e.g., flooding, drought, wildfires) resulted in a dynamic ecosystem where different vegetation communities may have naturally occurred at a single location over time. Therefore, the precise distribution of historical vegetation communities at the refuge likely varied depending on climatic conditions (e.g., van der Valk and Davis 1978). The distribution of native wetland plant species reflected adaptations to variable timing, depth, duration, and extent of annual flooding (hydroperiod) and underlying soil characteristics. Select native plant species known and expected to occur are listed for each habitat type described below (nomenclature follows the Integrated Taxonomic Information System, http://www.itis.gov, accessed June 2014).

Considering annual variation in precipitation and flooding regimes, we developed an HGM matrix of potential historical vegetation communities related to geomorphic landform, soil types, and hydrologic regime (Table 4). These vegetation communities were then mapped (Fig. 18) based on characteristics and distribution of soil types (Table 1, Fig. 4), vegetation communities recorded in GLO survey notes and maps from the late-1800s (e.g., Fig. 13) (Spray 1873a,b, Spray 1875), and life history characteristics of native plants (e.g., Hitchcock and Cronquist 1973, Wilson et

Table 4. Hydrogeomorphic (HGM) matrix of historical vegetation communities modeled for Conboy Lake National Wildlife Refuge in relationship to geologic landform, parent material, soils, and hydrological regime. Relationships were determined based on GLO maps and survey notes (Spray 1973a,b, 1875), mapped soil types and series descriptions, and characteristics of native vegetation communities (e.g., Hitchcock and Cronquist 1973, Wilson et al. 2008).

Habitat Type	Geologic Landform	Parent Material	Soil Type(s)	Hydrologic Regime
Ponderosa Pine Forest - Upland Meadow	Toe slopes	Alluvium & colluvium	Fanal sandy loam	Dry
	Low terraces	Alluvium	Glen sandy loam	
	Mountain footslopes	Volcanic ash & colluvium	Guler stony sandy loam	
	Low terraces	Alluvium	Kreft sandy loam	
	Lacustrine terraces	"	Sedigal sandy loam	
	Terraces	Volcanic ash & alluvium	Pinbit v. stony sandy loam	
Mixed Pine-Fir Forest	Canyon side slopes	Colluvium	Beezee cobbly loam	Dry
	Mountains & foothills	"	Kaiders stony loam	
	Mountains	Colluvium over residuum	Panak loam	
	"	"	Panak cobbly loam	
	Mountains & benches	Residuum & colluvium	Underwood loam	
	Canyon side slopes	Colluvium	Mazdale v. stony loam	
Wet Meadow - Emergent Marsh	Lake basins	Mixed alluvium	Conboy clay loam	Seasonal
	Lacustrine terraces	Lacustrine & alluvium	Grayland silty clay loam	
Open Water - Submerged Aquatic Vegetation	Lake basins	Mixed alluvium	Conboy clay loam	Semi-permanent to permanent
	Lacustrine terraces	Lacustrine & alluvium	Grayland silty clay loam	
Riparian Marsh	Varies	Varies	Fluvaquent Endoqualls	Seasonal to semi-permanent
			Various well drained soils	

al. 2008). The extent of hydric soils did not exactly match the extent of flooded area mapped by GLO surveyors. Therefore, the distribution of HGM-predicted vegetation communities assumes the following:

1. Areas of Conboy and Grayland series soil types not mapped as "wet prairie" during the GLO surveys were assumed dry at the time of survey. Given the poorly drained characteristics of these soils, we mapped these areas as wetland due to their hydric classification. We believe this assumption is valid because some areas of "overflow" were noted in the GLO survey notes that were outside of mapped "wet prairie."

2. Riparian marsh vegetation was mapped on well-drained soil types when GLO survey maps and notes recorded "wet prairie" vegetation and/or symbols. Wetland vegetation in these well-drained soils was likely maintained by the interaction of ground and surface water fluxes along stream channels.

3. The natural drainage classes of soils have not been affected by anthropogenic actions because alterations (e.g., ditches, berms) have not significantly changed the morphology of the soil (Soil Survey Division Staff 1993).

Although useful for understanding general surface water flow patterns, elevation data were not used to delineate historical vegetation communities due to its relatively coarse detail (e.g., 10-meter DEM). Historical elevation data recently located by USFWS may be useful to further refine the distribution of site-specific vegetation communities when additional hydrologic data is available.

Mixed Pine-Fir Forests

Pine and fir-dominated forests occurred on loamy soils on mountain slopes surrounding the Glenwood Valley. Within CLNWR, forested habitats were mapped on five different loam soil types predominantly along the diagonal southern border and in the southwest corner of the approved refuge area. Forested areas were dominated by ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*). Oregon white oak (*Quercus garryana*), lodgepole pine (*P. contorta*), and grand fir (*Abies grandis*) also occurred in these forested areas.

Understory species included regenerating pine and fir saplings, hazel (*Corylus americana*), buck

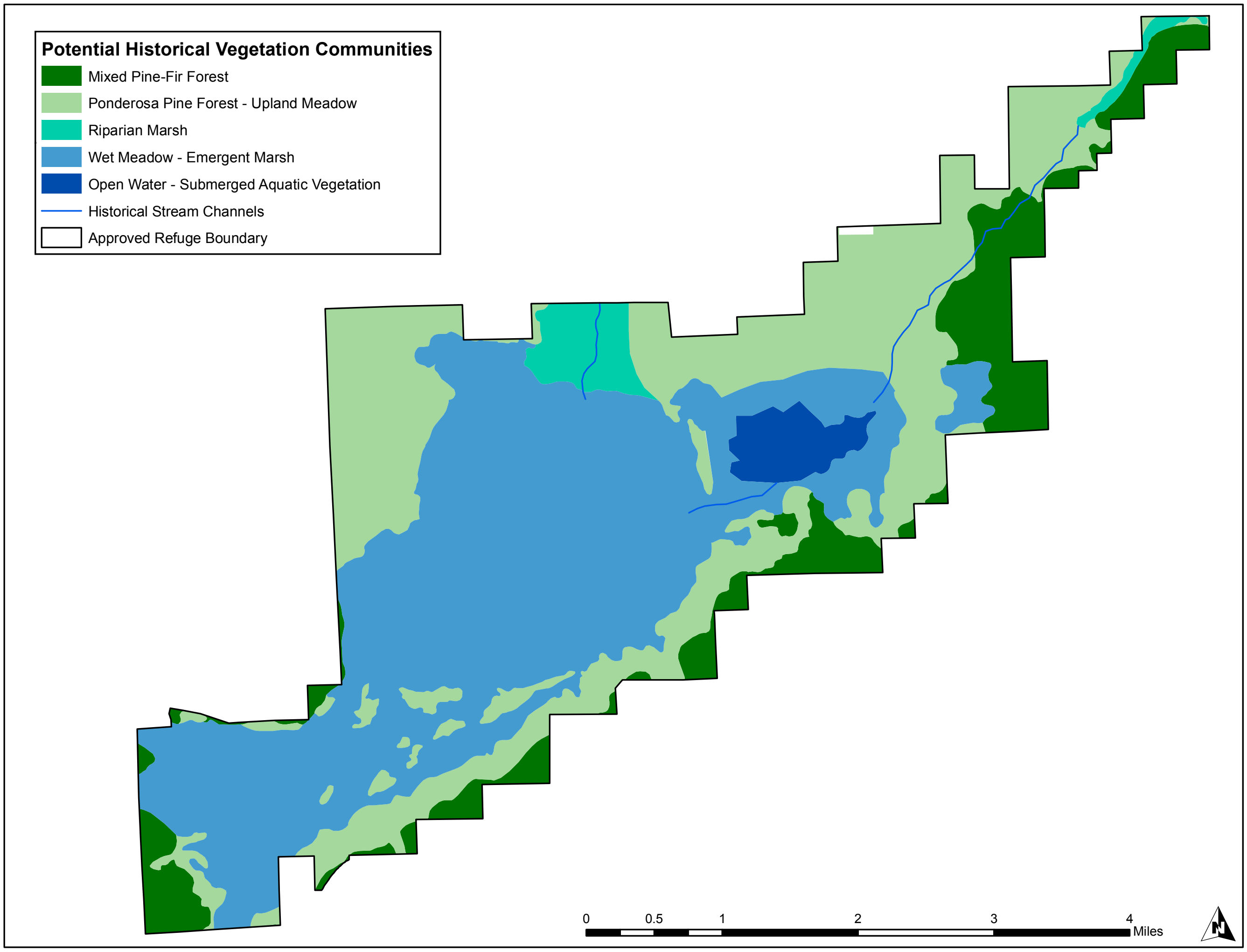

Figure 18. The extent and distribution of potential historical vegetation communities at Conboy Lake National Wildlife Refuge modeled from NRCS soil survey maps and series descriptions, historical GLO survey notes and maps (Spray 1873a,b,1875), and characteristics of native plants (e.g. Hitchcock and Cronquist 1973, Wilson et al. 2008).

brush (likely *Ceanothus sanguineus*), wild cherry (*Prunus* sp.), arrow wood (*Viburnum* sp.), scrub oak (*Quercus* sp.), willow (*Salix* sp.) and vine maple (*Acer circinatum*). Long-rhizome sedge (*Carex inops*) is associated with dry conifer forests in the Cascades and with Oregon white oak (Wilson et al. 2008) and likely occurred in this habitat at the refuge.

Ponderosa Pine Forests and Upland Meadows

Scattered pine trees with extensive bunchgrasses occurred on the east slopes of the Cascades and the northern part of the Glenwood Valley (Stevens 1860, Spray 1875). An 1853 description from Captain McClellan's Explorations of the east slope of the Cascades down from Klickitat Pass describes "forests more open and traversable, consisting of yellow pine [Ponderosa pine], with little undergrowth, and generally a grassy sward beneath." (Stevens 1860). Historical accounts refer to two saw mills near Glenwood that ". . .are turning out the choicest white and yellow pine lumber" (The Oregonian 1912b). Within CLNWR, this open pine forest-bunchgrass meadow habitat was mapped on six sandy loam soil types (Table 4) in the north and northwest areas of the approved refuge area (Fig. 18).

"Fine," "very good," and "plentiful" bunchgrasses and pinegrass (*Calamagrostis rubescens*) within pine trees were often noted in GLO surveys (e.g., Spray 1875). Bunchgrasses likely included bluebunch wheatgrass (*Pseudoroegneria spicata*), Idaho fescue (*Festuca idahoensis*), and blue wildrye (*Elymus glaucus*) (USFWS 2014). Elk sedge (*C. geyeri*), an important soil stabilizer with root masses extending almost 6 feet deep, is often a dominate species with pinegrass or Idaho fescue (Wilson et al. 2008). Other sedges that were likely common in bunchgrass meadows and forest openings include Hood's sedge (*C. hoodii*), Merten's sedge (*C. mertensii*), small-wing sedge (*C. microptera*), Liddon sedge (*C. petasata*), and Ross' sedge (*C. rossii*)

Native forbs likely included Oregon checkermallow (*Sidalcea oregana*), western yarrow (*Achillea millifolium*), Hooker balsamroot (*Balsamorhiza hookeri*), and several other species of asters (*Asteraceae*). North of the approved refuge boundary, patches of greasewood (likely *Ceanothus velutinus*) were recorded in GLO survey notes. Otherwise, understory shrubs were very limited within the open pine forest-bunchgrass meadow habitat.

Openings in the ponderosa pine forests were maintained by frequent low intensity ground fires (White 2009) and supported extensive grassland-forb communities. Suksdorf's milk-vetch (*Astragalus pulsiferae* var. *suksdorfii*) and Pulsifer's monkey-flower (*Mimulus pulsiferae*) are two plants associated with these openings (USFWS 2009). Patches of wet prairie occurred within this habitat type north of Conboy Lake, but the current soil map is not at a fine enough scale to show these inclusions.

Wet Meadow and Emergent Marsh

Lacustrine and alluvial deposits at CLNWR contain fine clay and loam-type sediments transported to the area by streams, glacial outburst floods, and Pleistocene lahars. These areas, typically topographic depressions where fine-grained sediments were held in suspension, historically supported wet prairie and emergent marsh habitats. Water levels in high elevation wet meadows were controlled by a combination of groundwater fluxes at hillslope boundaries, basal flow, snowmelt and precipitation within the meadow, and runoff and associated changes in stream stage (e.g., Lowry et al. 2010). Groundwater discharge from various springs that flowed through small channels or brooks into the Camas Prairie also hydrated wet meadow habitats.

Wet prairie and marsh habitats were mapped on Conboy clay loam and Grayland silty clay loam soils within the approved refuge boundary (Fig. 18). During 1855, the Glenwood Valley was described as "low and wet in many places, [with] evidence of being partially, if not entirely, under water during the wet season" (J.K. Duncan in Stevens 1860). During 1873, Spray (1873b:108) described the marsh as part of Camas Lake, ". . . the water of which is from one to six feet deep and spreads over an area of about seven thousand acres." During October 1875, water depths ranged from 1 to 3 feet in the "marsh," or Camas Prairie (Spray 1875). "Marsh," "meadow," and "prairie" habitats were recorded around open water habitats within Conboy Lake. Cranberries (*Vaccinium* sp.) and willows were noted at various locations within the marsh, but no other information is available to distinguish the plant species within the different vegetation zones (Spray 1875). The terms "prairie" and "marsh" may have been used interchangeably depending on hydrologic conditions. For example, during early September 1873, the west end of the prairie was apparently dry (Spray 1873a); during October 1873 the south portion of the prairie was wet (water 1 to 2 feet deep) and often referred to as "prairie marsh" (Spray 1873b).

The historical Camas Prairie area was named after the characteristic camas (*Camassia quamash*) that was historically abundant in the valley. Camas grows on areas that are moist to wet in spring but dry by late spring or summer (Hitchcock and Cronquist 1973). Camas is fire tolerant as the soil insulates meristematic tissue in camas bulbs (Turner and Bell 1971). It is known to increase after fire in others areas of Washington (Antieau and Gaynor 1990) and likely survived periodic low intensity fires that occurred in the marsh during dry periods.

Species associated with seasonally moist conditions in drier portions of wet meadows include tufted hairgrass (*Deschampsia cespitosa*), slenderbeak sedge (*C. athrostachya*), woolly sedge (*C. pellita*), pale broom sedge (*C. subfusca*), and tender sedge (*C. tenera*). Thick-headed sedge (*C. pachystachya*) is widespread in transition zones between wet and dry habitats. Merten's rush (*Juncus mertensianus*) and Nevada rush (*J. nevadensis*) were also found in dry to wet meadows. Inflated sedge (*C. vesicaria*) likely occurred in shallow water areas of wet meadows.

In wet sedge meadows, 50 to 75% of the biomass is below ground, where it plays an important role in stabilizing soils (Wilson et al. 2008). Short-beak sedge (*C. simulata*) likely occurred in wet meadows where the water table is at or above the surface until late summer and was important for stabilizing soils. Northwest Territory sedge (*C. utriculata*) can tolerate flooding up to 16 inches in the spring and groundwater to 2 feet below the surface in late summer. Water sedge (*C. aquatilis*) was likely common in wetter portions of the prairie where water persisted in the early summer and soil moisture was high all year. Western inflated sedge (*C. exsiccata*) can withstand flooding during winter, which was relatively common in the Camas Prairie as a result of increased fall precipitation and decreased evapotranspiration. Awned flatsedge (*Cyperus squarrosus*) was collected from west Klickitat County during 1881 from "wet grounds" (Consortium of Pacific Northwest Herbaria 2014).

Several species of rushes that likely were present in wet meadow habitats include Baltic rush (*J. balticus*), jointed rush (*J. articulates*), toad rush (*J. bufonius*), Colorado rush (*J. confusus*), Coville's rush (*J. covillei*), swordleaf rush (*J. ensifolius*), straightleaf rush (*J. orthophyllus*), western rush (*J. occidentalis*) and Torrey rush (*J. torreyi*). Mare's tail (*Hippuris vulgaris*) was likely common on areas of exposed mudflats during the summer. Panicled bulrush (*Scirpus microcarpus*) and threeway sedge (*Dulichium arundinaceum*) were also likely common in seasonally flooded wet meadow habitats. The seeds of awl-fruit sedge (*C. stipata*) in marshes disperse by floating.

Plants characteristic of freshwater emergent marshes in Washington with longer hydroperiods (e.g., flooded throughout the growing season in most years) include broadleaf arrowhead (*Sagittaria latifolia*), narrowleaf burreed (*Sparganium angustifolium*), broadfruit burreed (*S. eurycarpum*), hardstem bulrush (*Schoenoplectus acutus*), and softstem bulrush (*S. tabernaemontani*) (Rocchio and Crawford 2009). These species likely occurred in emergent marsh habitats around Conboy Lake and within deeper portions of wet meadows throughout the Camas Prairie.

Rare plant species associated with wet prairie habitats that were likely abundant before the Camas Prairie was drained include Oregon coyote-thistle (*Eryngium petiolatum*), rosy owl's-clover (*Orthocarpus bracteosus*), Kellogg's rush (*J. kelloggii*), dwarf rush (*J. hemiendytus* var. *hemiendytus*), long-bearded sego lily (*Calochortus longebarbatus* var. *longebarbatus*), and Gray's broomrape (*Orobranche californica grayana*). Oregon coyote thistle, rosy-owl's clover, and long-bearded sego lily are associated with moist to wet meadows that dry by summer.

Open Water/Submerged Aquatic Vegetation

Semi-permanently flooded and permanently flooded wetlands within CLNWR occurred at the historical Conboy Lake (see Fig. 13) and possibly deeper depressions in the Camas Prairie marsh. During 1855, Lieutenant J. K. Duncan described Conboy Lake as a "marshy lake, a mile and a half long" (Stevens 1860). Water levels fluctuated depending on surface and groundwater inputs. The maximum recorded extent of Conboy Lake after European settlement was about 7,000 acres (Spray 1873a,b). The mapped extent of open water during 1875 was near the beginning of a wet period (Cook et al. 2007) and, therefore, likely would have been larger in subsequent years. The area of open water would have decreased during dry periods when conditions were suitable for germination of emergent vegetation on exposed, saturated, and bare substrates. Groundwater discharge through springs, stream flow during wet years, and impoundment of water by beaver (*Castor canadensis*) also contributed perennial water to some areas. Open water areas were likely dominated by submerged aquatic vegetation such as sago pondweed (*Stuckenia pectinata*) and other pondweeds (*Potamogeton* sp.), slender naiad (*Najas flexilis*), and milfoil (*Myriophyllum* sp.).

Riparian Marsh

The GLO survey map shows the channel for Bird Creek surrounded by wetland habitat (Fig. 13). This riparian marsh habitat occurred on several well drained soils along Bird and Outlet creeks. This habitat type was maintained by interactions of ground and surface water in the floodplain of the stream channel. Riparian marsh habitat was also mapped on Fluvaquentic Endoaquolls along the Outlet Creek channel.

Sedges important in stabilizing streamside soils east of the Cascade Mountains include Nebraska sedge (*C. nebrascensis*), water sedge, common meadow sedge (*C. angustata*), and Northwest Territory sedge (Wilson et al. 2008); these were likely abundant in riparian marshes along the creeks entering CLNWR. Big-leaf sedge (*C. ampifolia*), Bolander's sedge (*C. bolanderi*), two-seed sedge (*C. disperma*), and fragile sheath sedge (*C. fracta*) were likely present in shaded stream reaches. Bolander's sedge was most likely found in riparian corridors that flowed through open pine woodlands. Greenfruit sedge (*C. interrupta*), which likely occurred along the major streams in the Klickitat Subbasin, colonized coarse sandy soils exposed after flood events (Wilson et al. 2008).

Key Animal Species

The historical wetlands of Camas Prairie and Conboy Lake, and surrounding forests supported a diverse assemblage of wildlife species, including ungulates and other mammals, waterfowl, passerines, fish, amphibians, and reptiles. Although relatively little historical information is available about the presence or abundance of wildlife species at CLNWR, a few accounts are noteworthy. During 1872, abundant wildlife noted by Cody Chapman included ducks, geese, swans (*Cygnus* sp.), sandhill cranes (*Grus canadensis*), and snipe (likely *Gallinago delicata*) (Cole, no date). Long-time residents of the area referred to "millions of ducks, geese, and swans" that used Camas Prairie and the historical Conboy Lake at the turn of the century (USFWS 1966 refuge annual narrative). Although no written records are known that confirm the presence of breeding trumpeter swans (*C. buccinator*) on Conboy Lake, local residents recalled them being present throughout the summer and collected trumpeter swan eggs during 1896-1906 (USFWS 1966 refuge annual narrative). Eggs of sandhill cranes were also collected at Camas Prairie during 1896 (Cole, no date).

Waterfowl reported at the refuge include northern pintail (*Anas acuta*), green-winged teal (*A. crecca*), mallards (*A. platyrhynchos*), lesser scaup (*Aythya affinis*), Canada geese (*Branta canadensis*), and tundra swans (*C. columbianus*). Other waterbird species reported on the area include Wilson's phalaropes (*Phalaropus tricolor*), American coots (*Fulica americana*), pied-billed grebes (*Podilymbus podiceps),* western grebes (*Aechmophorus occidentalis*), and great blue herons (*Ardea herodias*) (USFWS refuge annual narratives). Other avian species that occur are summarized by USFWS (2014).

Beaver (*Castor canadensis*) were likely very abundant in the Klickitat Subbasin, changing hydrologic processes and the resulting response of vegetation communities. Beaver, known as ecosystem engineers, affected surface and groundwater processes in the near-pond area as well as downstream of dams (Westbrook et al. 2006). Beaver dams enhanced the depth, extent, duration of water inundation associated with floods, increase aquifer recharge upstream of the dam, and attenuated the expected water table decline in the drier summer months in portions of the riparian floodplain (Lowry 1993, Westbrook et al. 2006). During the 1970s, beavers created "good quality waterfowl habitat" by damming and backing up water in drainage ditches (USFWS refuge annual narratives).

Mammals important to Native Americans in the region that were likely abundant in the Glenwood valley included mule deer (*Odocoileus hemionus*), black-tailed deer (*Odocoileus hemionus hemionus*), black bear (*Ursus americanus*), beaver, porcupine (*Erethizon dorsatus*), and hares (*Lepus* sp.) (Daugherty 1997). During the 1870s, a bear wallow at Camas Prairie was noted in GLO survey notes; otherwise, early records of mammal species are sparse. River otters (*Lontra canadensis*) were noted in refuge annual narratives during the 1970s, but no information on historical abundance was provided. River otters were likely abundant because they prefer marshes with interconnected meandering streams and beaver-influenced habitats (see summary in Melquist et al. 2003). River otters can travel large overland distances crossing mountain ranges and between drainages to disperse to suitable habitat.

#36-Camas and buttercup. Scenes like these attract flower lovers to the Glenwood Valley in the spring and early summer. 88-HC

PHOTOS FROM REFUGE ANNUAL NARRATIVES

#14-Whitcomb Cabin about 1899. This photo came from the Orie Kreps family via Mrs. Anne Ward of Trout Lake. Orie is the young fellow on the stump. Note the lack of windows or doors in the east (right) end of the building. This photo provides a wealth of information about the early days of the cabin and the pioneer life in the Glenwood Valley. 89-HC

CHANGES TO THE CONBOY LAKE ECOSYSTEM

OVERVIEW

This assessment utilized information obtained on contemporary: 1) physical features, 2) land use and management, 3) hydrology, 4) vegetation communities, and 5) fish and wildlife populations at CLNWR and the surrounding area. These data chronicle the history of land and ecosystem changes at and near the refuge during the European settlement period and provide perspective on when, how, and why alterations have occurred to ecological processes. Descriptions of chronological changes in physical features, settlement, land use/management of the region, and plant and animal populations are mostly available from Adams (1992), USFWS annual narratives from the refuge, and various other historical accounts. Historical maps and aerial photos, especially from 1880 through 1960, are limited.

EARLY SETTLEMENT AND LAND USE CHANGES

The Glenwood Valley was first inhabited between 11,000 and 7,000 years ago as a summer camp area by Native Americans from the Yakama and Klickitat Tribes (Adams 1992). Native Americans established permanent year-round villages along the main rivers on the Columbia Plateau and used temporary subsistence camps at higher elevations during the summer. A trail that connected the Columbia River drainage to the south and the Yakima River drainage to the north was established along the east side of Camas Prairie (Spray 1973a). A second trail that was noted on GLO map connected Camas Prairie with huckleberry patches on Mount Adams. Plants used by Native Americans included camas, bitterroot (*Lewisia rediviva*), wild onion (*Allium* sp.), hazel, kinnikinik (*Arctostaphylos uva-ursi*), and oceanspray (*Holodiscus discolor*) (Daugherty 1997).

During the late 18th century, tribes of the Columbia Plateau acquired horses from Plains tribes, which increased the importance of overland routes (Adams 1992). During 1829-1833, a disease epidemic killed an estimated 90% of the populations of Native American tribes, which was followed by a devastating smallpox epidemic during the 1850s. Trappers, explorers, and immigrant workers had come through the Klickitat region by the 1850s. Yakima Pass was considered as a potential route for the Pacific Railroad during 1853-1855. Gold was discovered in the Colville area during 1855, attracting more than 30,000 immigrant workers. As conflicts between Euro-Americans and Native American tribes escalated in the following years, the U.S. Army used the overland trails established by Native Americans to gain control of the area. The Yakama Nation Reservation (formerly Yakima Indian Reservation) was established in 1859 for 14 different tribes.

The paucity of animal life noted in area during the 1850s may have been due to: the 1842 eruption of Mount St. Helens; environmental change following the Little Ice Age; seasonal movements of large game (and timing of observations); historical contingencies of mammalian biogeography; introduction of fire arms to Native American tribes (Adams 1992, Martin and Szuter 1999, Lyman and Wolverton 2002, Laliberte and Ripple 2003); and/or overharvest by early explorers, trappers, and market hunters. Animal populations in the region continued to decline through the late 1800s; the last timber wolf was killed during the 1880s near Goldendale and the last elk was shot during 1896 (Adams 1992). Sandhill cranes and trumpeter swans apparently stopped nesting in the Glenwood Valley by the late 1890s. Beaver populations declined drastically from 1835 to 1850 in the Upper Columbia River Basin as a result of overharvest (Johnson and Chance 1974), and thus, impacted riparian areas prior to most written accounts. During 1821-1849, The Hudson Bay Company rapidly expanded in the Pacific Northwest, an area that produced 8% of the 18.5 million hides and pelts exported from North America (Hammond 1993).

Klickitat County was established during 1859. Although trappers lived seasonally in the Glenwood Valley, the first permanent Euro-American settler, Peter Conboy, filed on his land during 1872; other settlers followed thereafter. Homesteads were built on the gentle slopes of the forest along the edge of the valley and early residents grazed domestic livestock. An area of plowed land was noted west of where Bird Creek entered Camas Prairie during 1875 (Spray 1875). A sawmill was built along Bird Creek during 1880 near what became the town of Glenwood. Another sawmill was built at Laurel; however, this community was not sustained once the nearby timber was cut (Adams 1992).

During the 19th century, ranching was the most feasible land use in the Glenwood Valley, where cattle and sheep grazed in the Camas Prairie and then were driven to market (Adams 1992). A dairy association at Fulda produced about 10,000 pounds of creamery butter and 8,000 pounds of full cream cheese annually (The Oregonian 1912b). During the 1880s, an estimated 63,000 to over 100,000 sheep grazed on lands at the base of Mount Adams. Severe winters during 1880-1881, 1889-1890, and 1893-1894 and associated livestock losses contributed to agricultural diversification into grain and hay along with cattle (Adams 1992). Ground in the northeastern part of the valley was tilled for cultivation of crops. However, due to the short growing season, row crops did not mature in many years.

The agricultural potential of the valley was often referenced in GLO survey notes. During 1873, surveyor Samuel J. Spray wrote that when the marsh is drained and recovered for agricultural purposes, it would become “a region of great fertility and productiveness” (Spray 1873b). Some early residents agreed and thought the region “could be greatly enhanced and its products be increased many fold by draining the excessive waters of the lake” (The Enterprise 1911). Other residents were resistant to the proposed drainage project for financial reasons, but following court approval, construction of the drainage ditches started on 1 August 1911.

CONTEMPORARY LAND USE AND HYDROLOGIC CHANGES

The primary alterations to land within and near CLNWR include the following: 1) drainage of Camas Prairie and Conboy Lake wetlands through Camas Ditch and Outlet Creek; 2) channelization of creeks flowing into Camas Prairie and Conboy Lake and associated changes in both riparian and hydrologic characteristics; and 3) altered topography due to roads, dikes, ditches, borrow areas, and water control structures at and surrounding the refuge.

A local drainage district was formed during the early 1900s and engineering assessments determined it was feasible to drain the valley for agriculture. Fifteen and a half miles of main and lateral ditches were constructed through the Camas Prairie and Conboy Lake during 1911-1913 with a steam shovel drawn by horses. The Main Ditch (Camas Ditch and Outlet Creek) was five and a half miles in length, with the average top width of 26 feet (The Enterprise 1911). With the ditch partially completed by June 1912, settlers started seeding grain and hay. It was anticipated that several cuttings of alfalfa and other crops could be made compared to the previous single harvest of wild hay (The Oregonian 1912a). In addition to draining Camas Prairie and Conboy Lake, ditches were dug to keep creek flow within the banks of the constructed canal and reduced, if not eliminated, overland sheetflow that historically occurred along Bird Creek and other tributaries.

During 1908, farmers from Glenwood Valley made water appropriations on Hell Roaring Creek, which is about 12 miles north of the valley. Water from Bird, Frazier, and Bacon creeks was used to irrigate approximately 500 acres of land, but not enough water was available to irrigate a second cutting of hay (The Goldendale Sentinel 1911). It was estimated that water from Hell Roaring Creek could irrigate 20,000 acres in the Glenwood Valley. Originally planned to carry 100 cfs, Hell Roaring Ditch was completed during June 1933 with a capacity of 50 cfs to provide irrigation water for croplands (The Enterprise 1933). At an elevation of approximately 3,200 feet, Hell Roaring Ditch diverts water from the Big Muddy and other tributary creeks on Mount Adams (Strachan and Pilson 2013). Downslope water from additional creek diversions contributes to the flow of Hell Roaring Ditch before it reaches the channelized Bird Creek, which contributed approximately 17 cfs (12,000 acre-feet) to Hell Roaring Ditch during 1974 (Cline 1976).

Drainage ditches and other hydrologic alterations reduced the historical "lake" from a maximum annual extent of about 6,000 to 7,000 acres down to a maximum of 3,000 acres. Drainage improvements caused the lakebed to go completely dry compared to an estimated 400 to 1,000 acres that historically remained flooded each year during the late summer (USFWS 1975 refuge annual narrative). The extent of agricultural lands within the refuge area during 1960 is shown in Fig. 19. Hell Roaring Irrigation Company straightened 0.25 miles of Frasier Creek through refuge lands during 1970. During 1975, the local drainage district widened and deepened (60' wide x 15' deep) Camas Ditch and Outlet Creek, which run through the middle of Conboy Lake. During 1977, Camas Ditch and Outlet Creek were dry for nearly their full lengths (7 miles). Although 1977 was not as dry as some years in the 1930s and 1940s, residents could not remember a drier year since 1900. Structures that had been placed in Outlet Creek during the first half of the 20th century were removed by 1977 (L. Wilson and J. Engler, USFWS, personal communication). These observations suggest that the canal and ditch system "improvements" effectively increased the rate of surface and subsurface water drainage during the last half of the 20th century.

Water quality has only been sampled periodically at CLNWR (e.g., Cline 1976, Hayes et al. 2005) so no assessment of the refuge has been made for 303(d) impaired waters in the state of Washington. Some streams in neighboring watersheds in similar landscapes as the Middle Klickitat Watershed are impaired for different pollutants (see summary in Strachan and Pilson 2013); additional sampling is needed to assess water quality in the Middle Klickitat Watershed.

In addition to the diversion of surface water and drainage of wetlands for irrigation on the Columbia Plateau, groundwater from the CPRAS is pumped as a primary water source for municipal, industrial, domestic, and irrigation uses. These water uses have resulted in an increase in aquifer levels where diverted surface water is applied for irrigation and a decrease in aquifer levels where groundwater is pumped (Drost et al. 1990). Changes in groundwater well levels in the unconsolidated sediment of the shallow alluvial aquifer in Glenwood Valley were not reported by Snyder and Haynes (2010). Groundwater levels in the Grande Ronde basalt southeast of Glenwood Valley near the Klickitat River were unchanged from 1984 to 2009. Other areas in Adams, Lincoln, Umatilla, and Morrow counties showed declines in groundwater levels up to 250 feet (Snyder and Haynes 2010).

REFUGE ESTABLISHMENT AND MANAGEMENT HISTORY

CLNWR was established during 1965 following authorization from the Migratory Bird Conservation Committee (MBCC) on 10 August 1964 (USFWS 2014). Under authorities of the Migratory Bird Treaty Act, the MBCC created the refuge for the following purposes (summarized by USFWS 2014):

1. Restoration of lands to former wetland habitat; and
2. Proposed water development and management will be based primarily on the needs for nesting waterfowl with secondary benefits to migrating ducks and geese.

During 2000, the MBCC identified the following additional purposes:

3. Migration and nesting habitat for many waterfowl species, including mallard, pintail, cinnamon teal, and wood ducks, as well as Canada geese;
4. One of three known nesting locations for sandhill cranes in Washington; and
5. Important wetlands used by resident wildlife as well as migratory waterfowl.

By the end of 1966, the USFWS had acquired 5,214 acres through acquisition (USFWS 2014), approximately 50% of the area within the original approved refuge boundary. Condemnation procedures started during 1971 for 1,217 acres, but this land was revested to the private landowners during 1982. By 2009, CLNWR included 6,380 acres in fee title (Fig. 20) and a 718-acre easement.

After establishment, the refuge was administered as a satellite of Toppenish National Wildlife Refuge with no permanently assigned staff. Water levels were not actively managed and no gauging

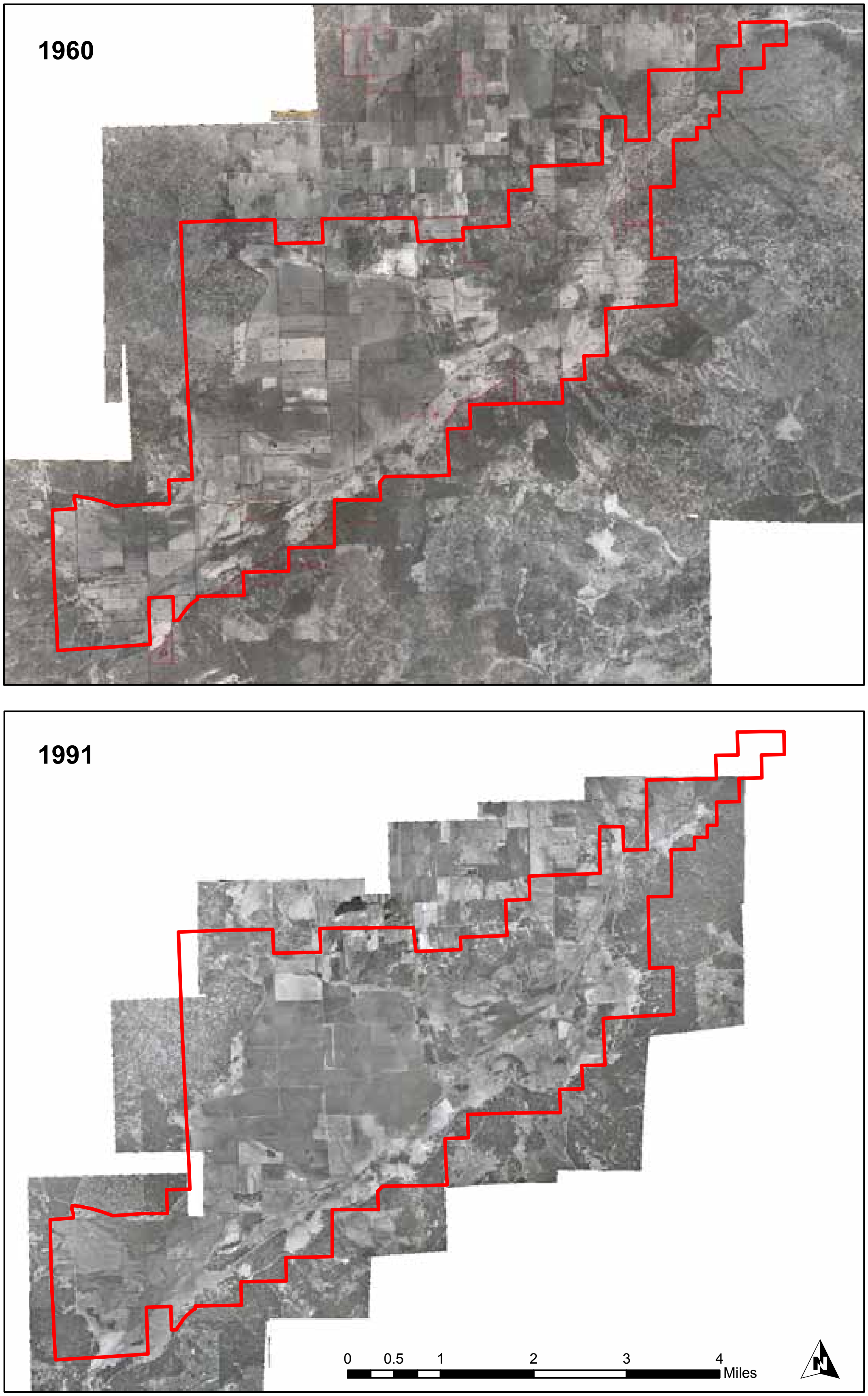

Figure 19. Aerial photographs of Conboy Lake National Wildlife Refuge during 1960 and 1991. (Data from USFWS refuge office files).

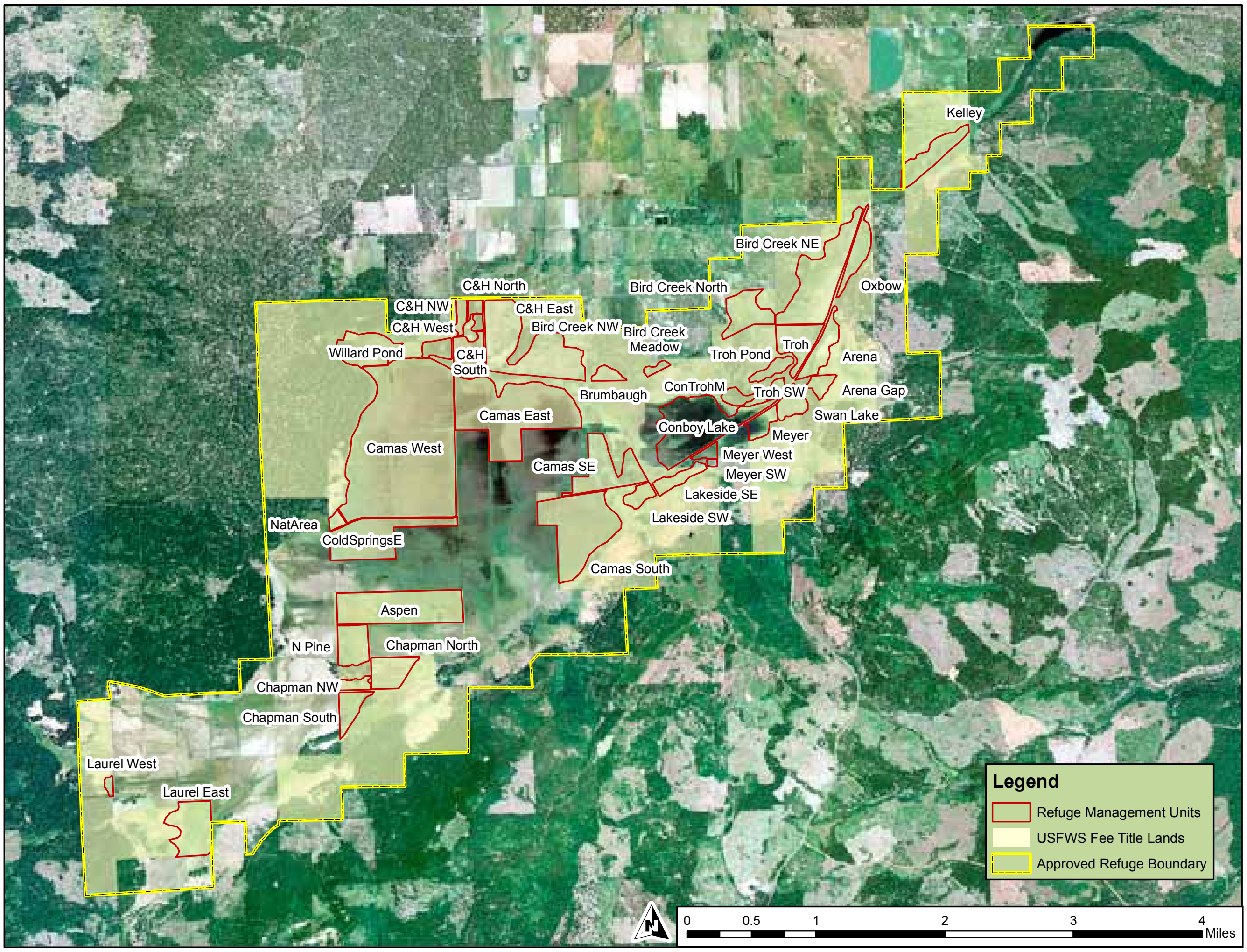

Figure 20. Fee title ownership and management units at Conboy Lake National Wildlife Refuge, Washington. (Data from USFWS refuge office GIS files; base imagery 2011 NAIP).

stations were present on the refuge. Early management activities were mostly limited to cleaning and maintaining existing ditches. During most years, Conboy Lake remained dry throughout the fall due to agricultural drainage of surrounding lands. The local drainage district and Hell Roaring Irrigation Company continued to straighten creek channels and deepen and widen existing ditches that ran through the refuge lands in order to drain hay lands and convey irrigation water.

During 1968, the first refuge-installed water-control structure was a wooden drop box used to divert water into the East Pasture. Wetland development actions at CLNWR increased during the mid-1970s and active manipulation of water levels began during 1976 (Table 5) (USFWS refuge annual narratives). Management during this time period focused on improving existing water delivery infrastructure that was originally developed for agricultural practices. Ditches, berms, and water-control structures were built or rehabilitated to facilitate control and delivery of water to wetland and hay units and prevent flooding impacts to neighboring landowners. Annual maintenance of existing ditches was also required to remove accumulated silt and sand.

Willard Pond was diked during 1977 to increase areas of permanent water and wetland habitats for waterfowl broods. During the early 1980s, wetland development actions began on the east part of the refuge. Additional water-control structures were installed during the 1980s to improve water delivery capabilities. Stoplog risers installed in the north bank of Camas Ditch and Outlet Creek allowed the refuge to hold permanent water at approximately the 1,815-foot contour (USFWS refuge annual nar-

Table 5. Chronology of developments at Conboy Lake National Wildlife Refuge. Summarized from USFWS refuge annual narratives.

Year	Refuge Management and Wetland Development Activities
1965	Conboy Lake National Wildlife Refuge established to restore former wetland habitats and provide habitat primarily for nesting waterfowl and secondarily for migrating ducks and geese.
1966	No active water level manipulations. The refuge was administered as a satellite of Toppenish National Wildlife Refuge with no permanently assigned staff.
1968	Installed wooden drop box for diversion of water into east pasture; cleaned 0.6 miles drainage ditch.
1969	Total refuge acres increased to 5313.35 ac.
1970	Hell Roaring Irrigation Company cleaned and straightened 0.75 miles of Frasier Creek that runs through refuge.
1975	Drainage District widened and deepened (60 feet wide by 15 feet deep) main drain that runs through middle of Conboy Lake.
1976	Refuge complexed with McNary National Wildlife Refuge.
	Installed several culverts and rock fills to facilitate water control; removed beaver dams and unplugged culverts.
	First year of active water manipulations.
1977	Cleaned 1.5 miles of Bird Creek ditch to eliminate bottleneck in water supply for northeast third of refuge and to prevent flooding of hay land; cleaned another ditch to connect Bird Creek ditch with Cold Springs ditch; installed 3 corrugated aluminum culverts with stoplog structures.
	Initiated "mini-master plan" to strategically place several small structures to deliver water on eastern quarter of refuge.
	Constructed new settling pond, where Bird Creek enters refuge, to reduce maintenance costs of continual ditch cleaning from silt during heavy runoff; 2 feet of sand deposited in settling pond trap by end of December.
	Constructed dike for new Willard Pond.
1979	Surveyed ground elevations for survey map.
	Constructed ditch around hand hewn log cabin to prevent water from nearby spring causing further damage to logs.
1980	Cleaned 2.5 miles of Bird Creek ditch; installed 3, 48-inch CMP stoplog structures in main channel; and installed 12 smaller structures in ditch banks to allow spreading of water over east end of refuge.
1981	Installed 30-foot culverts with half round stoplog risers in north bank of Camas Ditch-Outlet Creek to hold permanent water at approximately 1,815-foot contour and allow manipulation of several hundred acres of adjacent grasslands and wetlands.
1982	Refuge complexed with Lower Columbia River National Wildlife Refuge.
1983	Created potholes for brood habitat when sod removed to repair holes in Camas Ditch bank
1985	Refuge administered as a satellite of Ridgefield National Wildlife Refuge.
	Deepened and cleaned 2 miles of Cold Springs and Bird Creek ditch system and built up dikes in order to provide adequate water control capability
	Cleaned 1 mile of tributary ditch to allow water to be moved south and dropped into Conboy Lake lakebed.
1986	Rehabilitated south bank of Camas Ditch in hay unit 3-D; installed 3-foot CMP water control structure.
1987	New water system installed for fire suppression.
1988	Rehabilitated 3.75 miles of ditches on Cold Springs ditch upstream from Lakeside bridge, Bird Creek ditch upstream from Camas ditch, and several small feeder ditches on eastern portion of refuge.
1989-91	Prescribed burns initiated to set-back succession in Ponderosa pine stands.
1992-2002	No annual narratives available. The majority of functional water control structures were installed between 1998 and 2001 (L. Wilson, personal communication).
2003	Constructed berm and swale along Anderson Ditch to divert water away from private lands.
	Installed water control structure in Bird Creek and installed a spillway to drain Bird Creek southward.
	Filled a dike breach that continually drained the lake.
2004-10	No data available.
2011	Rehabilitated several spillways along Bird Creek and Conboy Lake; replaced several water control structures including a key structure where Bird Creek enters Outlet Ditch.

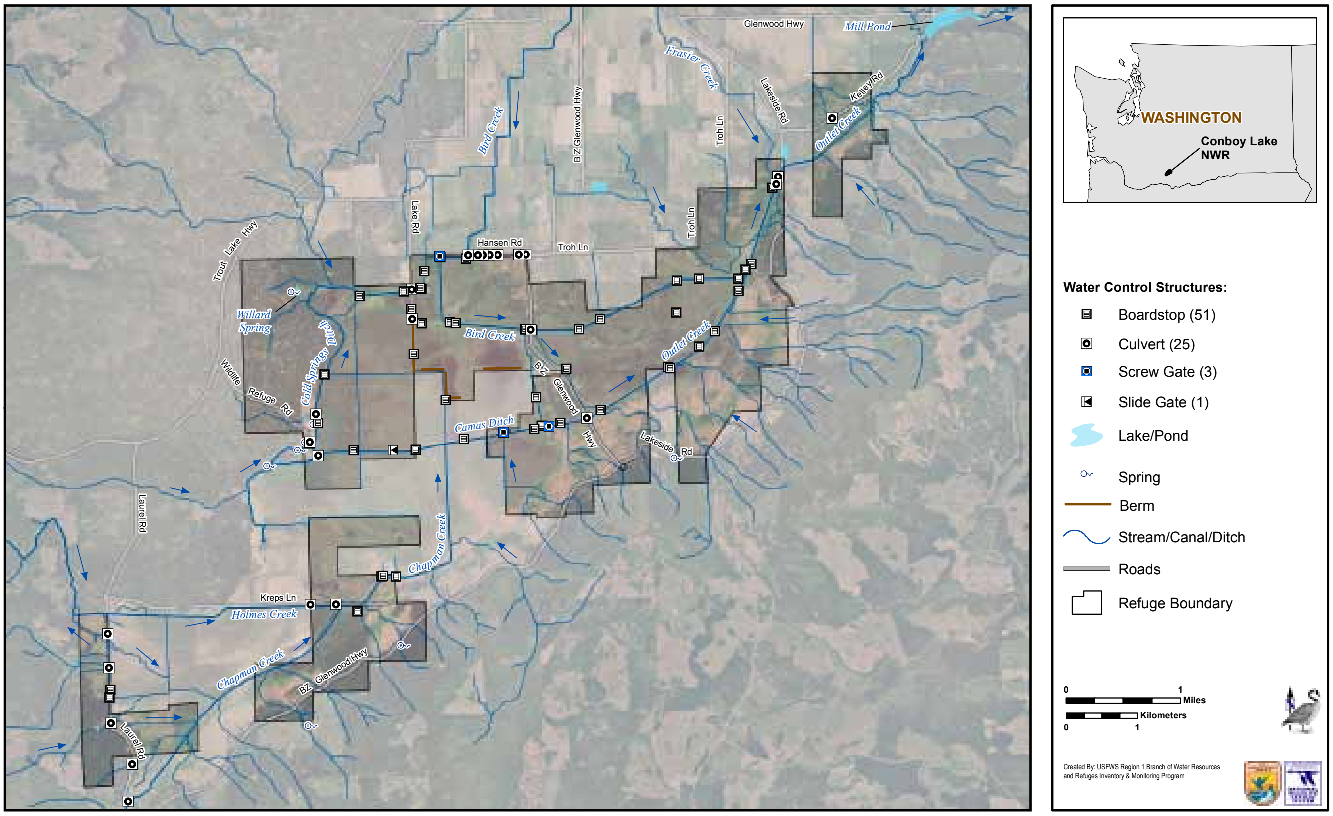

Figure 21. Streams, ditches, and water control structures at Conboy Lake National Wildlife Refuge. (From Strachan and Pilson 2013).

ratives). Comparing aerial photographs from 1960 and 1991 (Fig. 19), there appears be an increase in wetland habitats on the east part of the refuge near the historical Conboy Lake during that time period.

In addition to water developments, early land uses at CLNWR included haying and grazing. Grazing occurred from April to November on approximately 3,000 to 4,600 acres of refuge lands during the 1960s and 1970s; approximately 500 acres were hayed. Grazing was discontinued during 1976 and areas where cattle congregated started to re-vegetate within a year. The first prescribed burn was implemented during 1989 to set back succession of ponderosa pine stands.

Because refuge management is complicated by the land ownership pattern, proposals and discussions to develop flowage easement began in the 1980s. Easements and acquisition of inholdings are currently recognized as an important tool for restoring wetland habitats within Camas Prairie and Conboy Lake (USFWS 2005, 2009).

During 1998, USFWS started lowering dikes originally built 10-15 feet tall, in order to restore increased sheet flow, while still allowing the potential to hold water during dry years (J. Engler, USFWS, personal communication). Water was drawn off some units and timed to accommodate habitat management, including haying operations, and metamorphosis of Oregon spotted frog *(Rana pretiosa)* tadpoles. Currently, more than 100 miles of dikes, low-level berms, and drainage ditches are present at the refuge (USFWS 2005). Eighty water-control structures within the refuge (Fig. 21) (Strachan and Pilson 2013) are used to manage approximately 1,100 acres of seasonally flooded wetlands (Table 6). Prescribed burns have recently been implemented to manage wetland vegetation. For example, wetland habitats surrounding Willard Pond were burned during October 2013.

Although water levels have been measured at 26 staff gauges since 1999, only sporadic data are available electronically. Therefore, hydroperiods at managed seasonal wetlands on refuge lands cannot be assessed. However, water levels are managed for fairly consistent annual conditions that maximize breeding habitat for Oregon spotted frogs and allow for haying of non-native grasses. Areas of standing water at the refuge, based on NAIP imagery, are

Table 6. Current habitat types within acquired lands at Conboy Lake National Wildlife Refuge. Compiled from CNL_WRIA_RLGIS geodatabase (USFWS regional office files).

Habitat Type	Acres
Wet meadow (herbaceous)	2,219
Managed seasonal wetland	1,147
Emergent marsh	25
Permanent wetland	55
Scrub-shrub wet meadow	30
Aspen	20
Ponderosa pine	1,800
Mixed conifer-deciduous	365
Upland meadow	775
Developed	20
Total	6,457

similar during 2006, 2009, and 2011 (Fig. 22), despite below average water conditions 2009 and above average water conditions during 2011 (see Fig. 11). Annual water management practices on refuge lands includes initiating fall flood up around 1 October with the goal of the reaching "optimal" levels by 1 February (USFWS 2005). Summer drawdowns vary by unit depending on soil, water availability, and target habitat or species. Given existing infrastructure and landowner patterns, general water management and flow patterns from USFWS (2005) are summarized below.

Bird Creek provides the main source of water for wetland management at CLNWR. Water from Bird Creek is checked up to 1,822 feet at the Hansen Road tri-diversion by 1 October; water is then diverted to the west and/or south, where it is used to flood the Camas Prairie wetlands north of Camas Ditch. Water diverted to the west is initially used to fill the C&H management units with some water reaching the Willard unit. Water that flows south is used to fill Camas East as well as Conboy Lake and the Troh units east of the BZ Glenwood Highway. Bird Creek is also checked up after it crosses the Glenwood-BZ highway to: 1) back water into Bird Creek Northeast and Bird Creek marshes; 2) fill Conboy Lake and Aspen Meadow; and 3) allow sheetflow throughout the Troh area. Recent infrastructure improvements included fixing several spillways and replacing older water control structures along Bird Creek and Conboy Lake, including a key structure where Bird Creek enters Outlet Ditch that improves the ability of control water through the Troh area (L. Wilson, personal communication).

Cold Springs Ditch captures groundwater discharge from springs along the west boundary of the Camas Prairie; this water is then diverted to private lands or Camas West unit. However, the timing and duration of refuge water supply is dependent on private landowners and irrigation districts with senior water rights that control water flows.

Water from the channelized Holmes Creek is mostly diverted onto private land and ultimately flows south and east to Chapman Creek. Although this water can be important for managing refuge-owned land west of Laurel Road, the refuge has no rights to or management control of Holmes Creek water flow. In order for refuge wetlands to receive water from Chapman Creek during low water years, water levels must be checked within private lands to back up water into the Chapman Creek North and Aspen Grove refuge units.

Water from Frasier Creek and a series of ditches along Troh Lane also enters the refuge from the north. No infrastructure options are available to manage water in Frasier Creek and therefore most of the flow exits the refuge through Outlet Creek. Water flows in the Troh area ditches are highly variable (often called unreliable); however, water can be managed through the Gamble and Kelley tract. Irrigation tailwater from Bacon Creek enters the Kelley tract from the north. Improvements planned for this area entail moving surface water flow from the irrigation ditch to a natural channel within the Kelley tract (L. Wilson, personal communication).

CHANGES IN PLANT AND ANIMAL COMMUNITIES

Limited quantitative data are available to understand changes in plant and animal species at CLNWR. However, regional changes to native wildlife habitats in the Pacific Northwest since European settlement are apparent. Removal/reduction of Native American populations and their fire management practices, suppression of lightening-caused wildfires, introduction of non-native species, grazing of domestic livestock (e.g., sheep and cattle), and conversion of native habitats to agricultural lands have altered, destroyed, or increased fragmentation of native habitats throughout the Columbia Plateau and Eastern Cascade Mountains (e.g., Hessburg and Agee 2003). The major changes to vegetation communities on the refuge include the following: 1) decreased area of wetland habitats due to the drainage ditches and altered hydrology; 2) altered species composition of the Camas Prairie due to wetland drainage, hydrologic changes, grazing, invasive species, and conversion to agricultural lands; 3) encroachment of trees into wet meadow habitats; 4) altered forest dynamics due to historical logging and fire suppression; 5) decreased abundance of some native plant and animal species; and 6) increased abundance and distribution of non-native species.

Wetlands

Wetland habitats within the Glenwood Valley are classified by the USFWS National Wetland Inventory Program based on aerial imagery from the 1980s (Fig. 23). Palustrine emergent wetland types are the most extensive wetland type occurring on 5,541 acres within the approved refuge boundary. Forested shrub/scrub is the next most abundant wetland type on 545 acres. Current wetland habitat types within the acquired lands are classified as wet prairie/ wet meadow, emergent marsh, and alder and willow (Fig. 24).

The dominant plant species in the Camas Prairie at the time of refuge establishment was reed canary grass (*Phalaris arundinacea*), which was introduced to the valley as a pasture and hay grass. Compared to some native sedges (e.g., inflated sedge), lowered water tables resulting from drainage ditches create conditions that favor reed canary grass (Wilson et al. 2008). Improved water management on refuge lands during the 1980s replaced some reed canary grass and other upland species that had invaded the eastern portion of the refuge with bulrush, sedges, smartweed, and rushes. Other non-native plant species include Canada thistle (*Cirsium arvense*), bull thistle (*C. vulgare*), meadow knapweed (*Centaurea pratensis*), bachelor buttons (*C. cyanus*), diffuse knapweed (*C. diffusa*), common St. John's wort (*Hypericum perforatum*), and scotchbroom (*Cystis scoparius*).

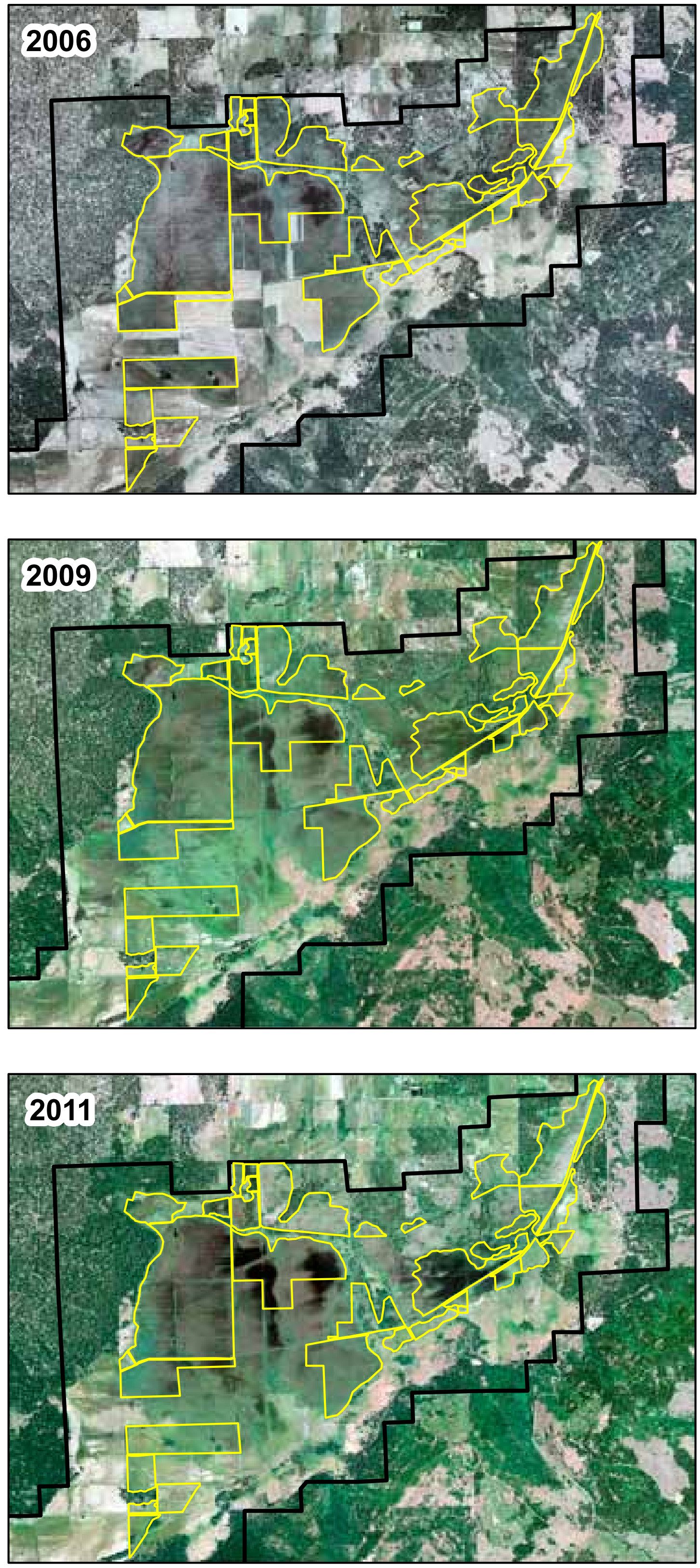

Figure 22. NAIP imagery from 2006, 2009, and 2011 of the central portion of Conboy Lake National Wildlife Refuge, Washington. Imagery from NRCS Geospatial Data Gateway (http://datagateway.nrcs.usda.gov/), and USFWS

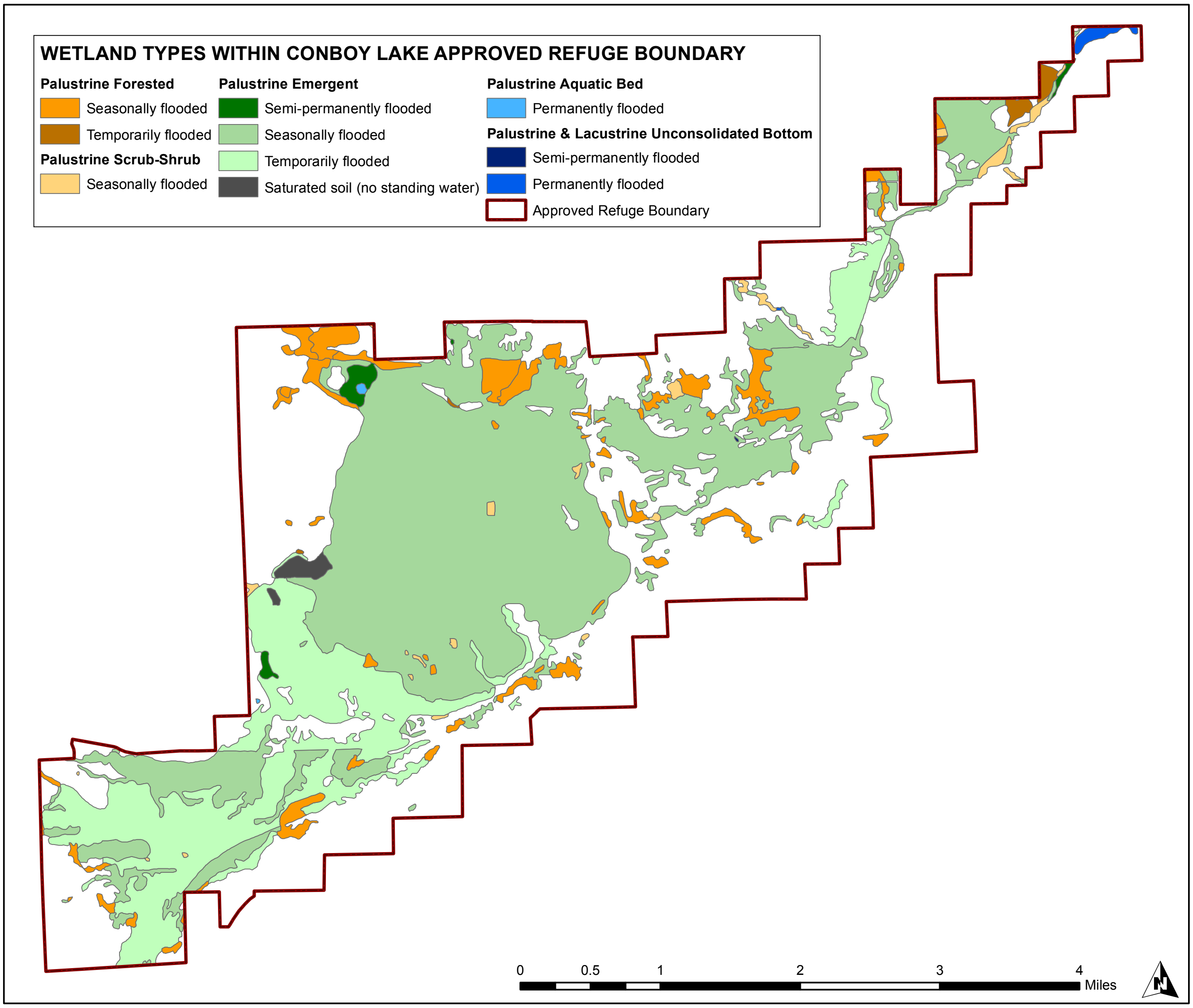

Figure 23. USFWS National Wetland Inventory classification of wetland habitats at Conboy Lake National Wildlife Refuge. Data from CNL_Report_Layers.mdb (USFWS Regional 1 geodatabase).

Drainage and channelization has impacted riparian and wet meadow species in the Glenwood Valley. Two-seed sedge is vulnerable to hydrologic changes and logging that removes shade (Wilson et al. 2008); this species has not been collected in Klickitat County since 1895 (Consortium of Pacific Northwest Herbaria 2014). Other riparian associated sedge species are likely greatly reduced in extent as a result of stream channelization and clearing of native woody vegetation for channel maintenance. In addition, some sedges and rushes historically present in drier portions of wet meadows (i.e., tender sedge, Merten's rush) have not been collected from Klickitat County since the 1880s and 1890s (Consortium of Pacific Northwest Herbaria 2014).

Oregon coyote thistle is only known from three locations within refuge-owned lands (Engler and Stutte 2010). Drainage of wet meadow habitats for farming and grazing, suppression of wildfires, and encroachment of shrubs and trees, and the introduction of non-native species have likely contributed to its reduced extent and relatively small population. Based on population estimates during 1992, 2004, and 2010, restoration of seasonal hydrology to wet meadow areas has likely contributed to an increase in population and area occupied by Oregon coyote thistle (Engler and Stutte 2010).

Rosy owl's-clover occurs at 11 different areas covering about 150 acres within acquired lands of CLNWR (Engler and Stutte 2005). Delayed haying from 1 July to 1 August and hydrologic restoration of wet meadow habitats likely increased the population and distribution of rosy owl's-clover from historically reduced numbers. However, limited historical survey data are available to assess the response of this species to refuge management actions. In addition, population numbers likely fluctuate in response to environmental conditions (Engler and Stutte 2005). Pulsifer's monkey flower is known at only one location near Willard Spring within the acquired boundary of the refuge (Stutte and Engler 2005). The location is generally drier than the moist meadows where it is usually found, but local groundwater may seasonally hydrate the soil. Dwarf rush and Kellogg's rush have also only been reported from one location within the acquired parcels (Engler 2007).

Suksdorf's bladderwort, a wetland plant described during the late 1800s from the Glenwood Valley, was not located during surveys conducted during 2000 (Engler 2007). Glenwood is one of three areas in Washington where California broomrape was historically collected (Camp and Gamon 2011); it was recently found at CLNWR in the Oxbow unit during 2013 (L. Wilson, personal communication).

Limited information is available on changes in waterfowl productivity and population estimates. However, long-time residents of the Glenwood Valley said that populations during the mid 1960s were greatly reduced compared to the early 1900s (USFWS 1966 refuge annual narrative). Mallards and green-winged teal were the most abundant duck species during 1966. Annual waterfowl use days during 1966-1970 ranged from 120,000 to 333,000

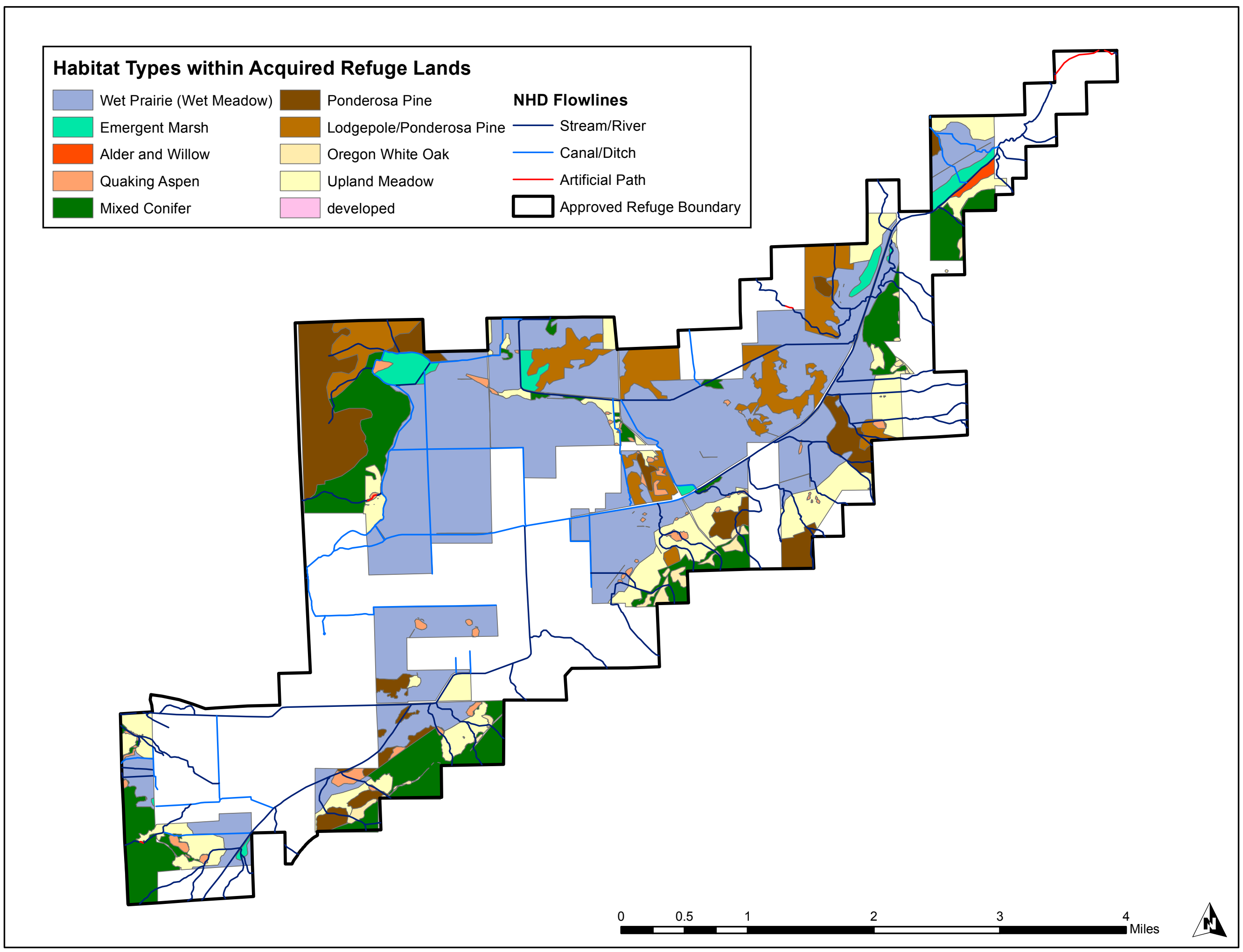

Figure 24. Habitat types within acquired refuge lands and surface water flow lines within the approved refuge boundary at Conboy Lake National Wildlife Refuge. Data from USFWS Region 1 Refuge Information Branch and USGS National Hydrographic Dataset (http://nhd.usgs.gov/).

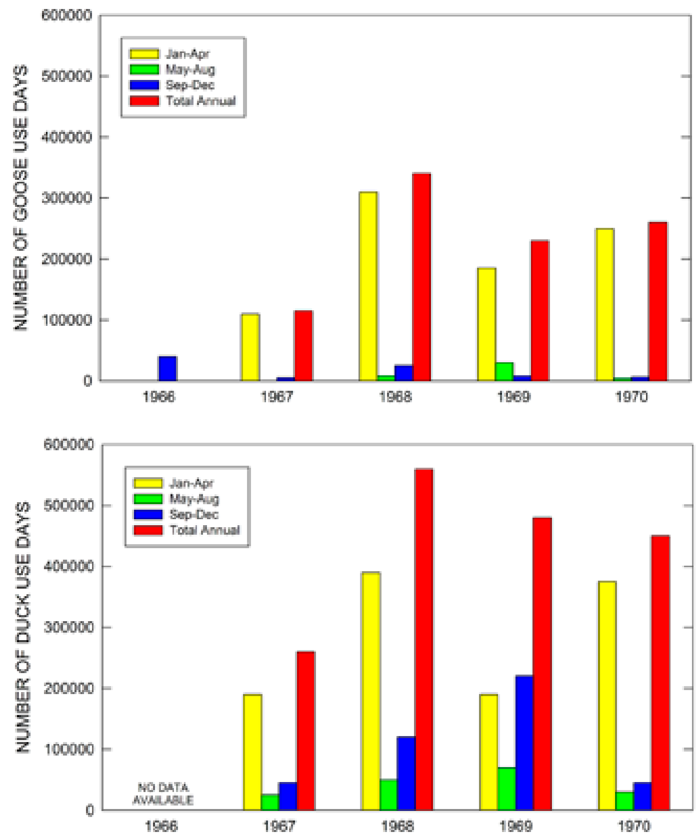

Figure 25. Number of duck use days and goose use days at Conboy Lake National Wildlife Refuge, 1966-1970. Data values estimated from graph in USFWS 1970 refuge annual narrative.

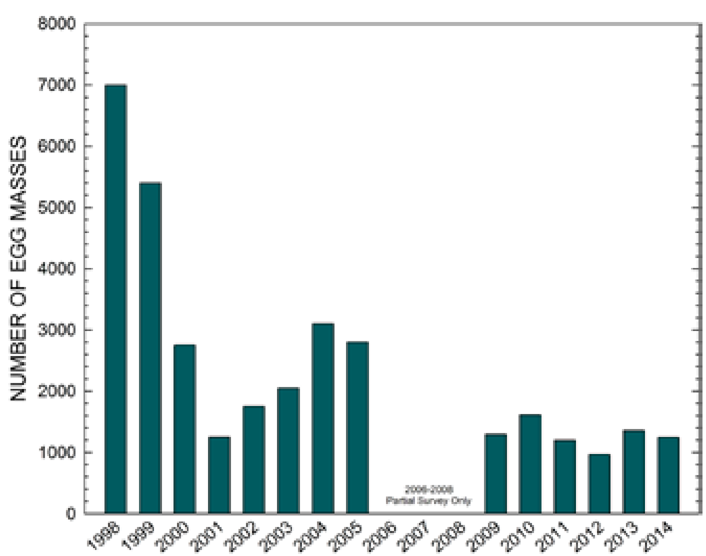

Figure 26. Egg masses of Oregon spotted frogs (*Rana pretiosa*) at Conboy Lake National Wildlife Refuge. Data compiled from Hayes and Hallock (2009), Hayes and Hicks (2011), and L. Wilson, USFWS, personal communication. Egg mass counts from 1999-2000 and 2002-2005 were estimated from graphs in Hayes and Hallock (2009).

for geese and 250,000 to 550,000 for ducks (Fig. 25). Following deepening and widening of the Main Ditch during 1975, duck use days decreased by about 66% (USFWS refuge annual narratives). Wetland improvements during the 1980s may have contributed to a rebound in duck use days. During 1981-1985 waterfowl use days averaged 264,300 for geese, 577,500 for ducks, and 23,300 for swans; duck production averaged 430 nests/year during (USFWS 1988).

After refuge establishment and increased water management for wetland habitats, sandhill cranes were first observed during fall 1972 and spring 1974 and the first nest attempt since the early 1900s was recorded during 1975 (USFWS refuge annual narratives). By 2009, the breeding population of sandhill cranes increased to 21 breeding pairs (USFWS 2009) and is currently estimated at approximately 25 pairs (USFWS 2014).

Oregon spotted frogs were "rediscovered" on CLNWR during 1992 (USFWS 2014). This species has declined throughout its historical range and currently is extant at only about 10-30% of its historical habitat (Cushman and Pearl 2007). Often indicative of imperiled species, Oregon spotted frogs have low genetic diversity and small effective population sizes (Phillipsen et al. 2011). The refuge currently supports one of the largest remaining populations of Oregon spotted frogs and it is one of several known extant locations in the state of Washington. Systematic egg mass surveys have been completed since 1998. Egg mass counts on units surveyed during all years ranged from 962 (2012) to >7,000 (1998) (Hayes and Hicks 2011). Since high counts during 1998 and 1999, egg mass numbers have fluctuated between 1,000 and 3,000 egg masses (Fig. 26) (Hayes and Hallock 2009, Hayes and Hicks 2011, L. Wilson, USFWS personal communication).

Most beaver populations were decimated by fur trappers during the 1800s (Bryce 1904 as cited in Baker and Hill 2003). The pattern of over-harvest documented in the Upper Columbia River Basin (Johnson and Chance 1974) likely occurred throughout the Lower Columbia River Basin as well. The near removal of beaver prior to most historical accounts of the area likely decreased alluvial sedimentation rates in valley bottom streams, increased stream channel incision and erosion, and modified biogeochemical characteristics of stream and riparian habitats (Baker and Hill 2003). During the 20th century, beaver populations periodically increased at CLNWR. For example, beaver were trapped extensively during the 1960s when increased populations interfered with drainage and irrigation practices (USFWS refuge annual narratives). Beaver have been allowed to remain in some areas of the refuge where they do not hamper water management objectives.

Non-native animal species introduced into wetland and stream habitats in the Glenwood Valley include bullfrogs (*Lithobates catesbeianus*), brown bullheads (*Ameiurus nebulosus*), eastern brook trout (*Salvelinus fontinalis*), rainbow trout (*Oncorhynchus mykiss*), and catfish (*Ictalurus punctatus*) (USFWS refuge annual narratives). Rainbow trout are stocked for fishing purposes, and brook trout are remnant populations from historical stocking efforts (USFWS 2014).

Bullfrogs were introduced throughout the Western U.S. during the early 1900s primarily for the harvest of frog legs (Hallock and McAllister 2009). Bullfrogs prey on a wide range of native species, including native anurans, which can be a large proportion of their diet (see Pearl et al. 2004). Oregon spotted frogs are particularly susceptible to predation by bullfrogs due to their affinity with aquatic habitats and reduced escape abilities when compared to other Ranid frogs (Pearl et al. 2004). In addition to effects of competition and predation, explosive breeders, such as Oregon spotted frogs, may also be negatively impacted by reproductive interference via interspecific amplexus (Pearl et al. 2005).

Uplands

Mapped upland habitat types currently present at CLNWR include ponderosa pine forest, lodgepole-ponderosa pine, mixed conifer, Oregon white oak, aspen, and upland meadows (Fig. 24). Approximately 2,000 acres of forested habitats occur within acquired refuge lands, primarily located along the edge of Camas Prairie. White (2009) categorizes forest stands at the refuge into five different types: 1) ponderosa pine stands; 2) lodgepole pine stands; 3) mixed conifer stands with Douglas-fir, ponderosa pine, and grand fir as the primary species; 4) quaking aspen stands; and 5) Oregon white oak woodlands in small patches usually associated with surrounding mixed conifer forests.

Current forest stands are dense from the lack of fire; forest canopy layers are lacking, snag density is low, and forest openings are lacking (USFWS 2009). The current ponderosa pine forests are relatively even-aged, second growth with evidence of early logging activities. Life-history strategies of nine focal bird species and one focal mammal species that use forested habitats have been identified to guide forest management at CLNWR (White 2009).

CLNWR is one of nine locations in Washington where mardon skippers (*Polites mardon*) are known to occur (Potter et al. 1999). Statewide its population is estimated at a few hundred individuals; historical population estimates are unknown. In the southern Cascades, it occurs in fescue-dominated grasslands within open ponderosa pine stands (Potter al. 1999). These bunchgrass dominated meadows provide important food plants, including various species of forbs and Idaho fescue, and substrates for oviposition. Altered hydrology has also likely impacted this species as mardon skippers use transition habitats between wet and dry meadows (L. Wilson, USFWS, personal communication).

Within the state of Washington, Suksdorf's milk-vetch is only known to occur at CLNWR and adjacent timber lands (Engler 2007, 2010). Fire suppression may be negatively impacting this species by increasing canopy closure in ponderosa pine forests and accumulating duff on the forest floor (Engler 2007). Suksdorf's milk-vetch is currently found in areas disturbed by logging or road-building within the past 75 years or in areas moderately to heavily disturbed by deer and elk (Engler 2010). Douglas' sedge (*C. douglasii*) occurs in open pine forests and may increase when taller more palatable plants are removed by livestock grazing (Wilson et al. 2008). Liddon sedge, which is an indicator of excellent range condition (Wilson et al. 2008), has not been collected in Klickitat County since 1890 (Consortium of Pacific Northwest Herbaria 2014).

PREDICTED IMPACTS OF CLIMATE CHANGE

Climatic trends in the Western U.S. during the 20th century may be related, in part, to the interdecadal climate variability associated with the Pacific Decadal Oscillation (PDO), as well as the monotonic warming, which is largely unrelated to the PDO (Knowles et al. 2006, Mote 2006). Temperatures in the Pacific Northwest are projected to increase from 1.5 to 5.2 degrees Fahrenheit by the 2040s and up to 9.7 degrees Fahrenheit by the 2080s (Mote and Salathé 2010). Predicted changes in total annual precipitation for the Pacific Northwest are equivocal ranging from -10 to +20%; however, most models predict summer precipitation will decrease and winter precipitation will increase likely related to changes in mid-latitude storm tracks (Yin 2005, Salathé et al. 2008, Mote and Salathé 2010, Bender et al. 2012). In addition, there is a statistically significant increase in extreme precipitation events worldwide that is expected to continue in the future, especially at northern latitudes (Tebaldi et al. 2006).

Warming is amplified by nearly 2 degrees Fahrenheit along the flanks of the Cascade Mountains and high elevation basins at the present-day snowline where lands are more sensitive to changes in temperature due to associated loss of snow cover and the snow-albedo feedback (Salathé et al. 2007, Salathé et al. 2008). At higher elevations on Mount Adams, trends in decreasing glacier area (Sitts et al. 2010) will likely continue as temperatures continue to increase. As a result, these temperature increases will extensively change water resources throughout the region. The most significant impact of this warming will be a reduced winter snowpack and the associated reduction in natural water storage (Barnett et al. 2004). Reduced natural water storage combined with higher summer temperatures and decreases in humidity will result in higher water temperatures, increased fire danger, and reduced ability to meet irrigation needs (Barnett et al. 2004).

Reduced snowpack and earlier stream flow appear to be greater or vary significantly from natural variability and are attributed to climate changes caused by anthropogenic greenhouse gases, ozone, aerosols, and land use (Pierce et al. 2008, Hidalgo et al. 2009). Various hydrologic and phenologic metrics suggest that warming has advanced the arrival of spring by 1-2 weeks in Western North America (Cayan et al. 2001). Modeled stream flow under a 'business as usual' climate change scenario suggest an even earlier stream flow than observed to date (Stewart et al. 2004). During 1948-2000, snowmelt and associated streamflow has advanced 5-15 days in south central Washington; it is predicted to advance another 15-35 days compared to 1951-1980 averages (Stewart et al. 2004). Earlier snowmelt and stream flow will affect the timing of surface water inputs into the Glenwood Valley and aquifer recharge in the Upper Klickitat Watershed. In addition, possible reductions in total annual stream flow and lower minimum flows (Cohen et al. 2000) may alter riparian communities in the Glenwood Valley.

Modeling of climate change impacts on groundwater resources worldwide is limited and results are highly variable due to the complex nature of aquifers (Green et al. 2011). It is not known if overall groundwater recharge will increase, decrease, or stay the same at any scale in the Western United States (Dettinger and Earman 2007 as cited in Green et al. 2011). However, changes in timing and amount of precipitation in the Cascade Mountains will undoubtedly affect timing and amount of recharge to the aquifer. Lower elevations of the Cascade Mountains are predicted to have the greatest differences in timing and magnitude of snowmelt recharge (e.g., Hayhoe et al. 2004, Payne et al. 2004). In addition, local variations in bedrock geology, aquifer volume, and seasonal fluxes of subsurface water will likely result in spatially variable responses of streamflow to climate change because young volcanic landscapes can exert a strong control on streamflow and trajectories of change (Tague et al. 2008). Differences in groundwater dynamics are as important as differences in topography in determining the response of mountain landscapes to climate change and should be considered as important as snowpack dynamics (Tague et al. 2008). If the increased probability of extreme high precipitation events observed in the 20th century continues to occur, then recharge to aquifers may decrease because of increased/accelerated surface water runoff that occurs during and immediately after high intensity precipitation events. Increased intensity of precipitation may also cause increased erosion from upland areas/mountain slopes and fans into valley wetland areas.

Predictions of future climate change are likely to have some effect on native vegetation communities in the Glenwood Valley. Increases in temperatures may extend the fire season and cause an increase in larger more severe fires in arid upland habitats throughout the Western United States. Warming temperatures, along with fire suppression and land-use changes, have contributed to an increase in severe stand replacing fires in ponderosa pine forests, as occurred during Holocene drought periods over the past 500 years (Pierce et al. 2004). Stand replacing fires in mixed pine-fir forests may also be influenced by warming (Velben et al. 2000). Increasing temperatures may also cause shifts in species distribution. Increased carbon dioxide (CO_2) may increase the growth of plants with C3 photosynthetic pathways, including both native and non-native species (Chambers 2008). This is a potential concern at CLNWR because the production of reed canary grass may increase under elevated CO_2 levels (Kao-Kniffin and Balser 2007), subsequently increasing in areas where it currently is not dominant. This would increase management challenges and costs associated with control efforts for reed canary grass.

Warming experiments decreased soil moisture and increased nitrogen mineralization in montane meadows (Harte et al. 1995, Shaw and Harte 2001). The response of high elevation native upland meadow forbs to warming is species specific with some species showing favorable responses (e.g., lower frost damage, larger flowering stalks) and/or negative responses (e.g., decreased abundance, flowering, and size) (de Valpine and Harte 2001). Increased carbon and nitrogen mineralization also occurred in warming experiments of soils from northern sedge wetlands (Updegraff et al. 1995).

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OPTIONS FOR ECOSYSTEM RESTORATION AND MANAGEMENT

SUMMARY OF HGM INFORMATION

Information obtained during this study was sufficient to conduct an HGM evaluation of historical and current ecological attributes of the CLNWR ecosystem. The refuge historically contained a unique mountain valley wetland ecosystem with the large seasonally flooded Camas Prairie and the namesake Conboy Lake. This wetland system was fed by surface water runoff in the Klickitat Subbasin, discharge of groundwater through various springs, hillslope groundwater dynamics, and local precipitation/snowmelt. Annual inputs of water (including surface water runoff and groundwater dynamics) were determined by the highly variable long-term pattern of local precipitation and snowpack on Mount Adams. The wetland complex was surrounded by native mesic to xeric upland meadows dominated by bunchgrasses, ponderosa pine, and mixed pine and fir forest communities.

The primary anthropogenic changes to the CLNWR lands and its surrounding ecosystem have been the following:

1. Drainage of Camas Prairie and Conboy Lake through Camas Ditch and Outlet Creek and associated changes in hydroperiod;
2. Channelization of creeks flowing into Camas Prairie and Conboy Lake and associated changes in both riparian and hydrologic characteristics;
3. Altered topography resulting from roads, dikes, ditches, borrow areas, and water control structures at CLNWR and surrounding lands;
4. Altered species composition of the Camas Prairie due to wetland drainage, hydrologic changes, grazing, haying, invasive species and conversion to agricultural lands.
5. Altered forest dynamics due to historical logging and fire suppression;
6. Encroachment of trees into wet meadow habitats;
7. Decreased abundance of some native plant and animal species; and
8. Increased abundance of non-native species.

A major challenge for the future management of the refuge will be to determine how to manage for more natural wetland and riparian processes that provide abundant resources for wetland-dependent wildlife given the substantial changes in water availability, existing water rights, and the varied ownership of the historical Camas Prairie wetlands.

RECOMMENDATIONS FOR ECOSYSTEM RESTORATION AND MANAGEMENT

This assessment identifies a range of restoration and management options that will protect and sustain natural ecosystem processes, functions, and, in turn, resource values at CLNWR. The refuge provides key resources to meet annual life history requirements for a diverse assemblage of native bird, mammal, and amphibian species that should be addressed within the context of a holistic system based on regional landscape objectives. CLNWR is an important area that also can provide opportunities for wildlife-dependent recreation and education. These public uses are important management issues; however, this study does not address where, or if, competing resources and public use can be accommodated on the refuge. This report provides ecological information to support resource management priorities identified for refuges in the National Wildlife Refuge System Administration Act of 1966, as amended (16 USC 668dd-668ee). Specifically, the National Wildlife Refuge Improvement Act of 1997 (Public Law 105-57) seeks to ensure that the biological integrity, diversity, and environmental health of the Refuge System are maintained. Step-down policies from the Act that articulate the importance of conserving "a diversity of fish, wildlife and plants and their habitats" and conserving unique, rare, or declining ecosystems (601 FW 1) include mandates for assessing a refuge's importance across multiple spatial scales and recognizing that restoration and/or management of historical natural processes is critical to achieve these goals (601 FW 3).

Considering USFWS policies and legal mandates guiding management of refuges, the HGM approach provides a basis for developing recommendations for the future management of CLNWR. Historical processes (those prior to substantial human related changes to the landscape) are considered as the benchmark (reference) condition for restoration and management (Meretsky et al. 2006), but restoration to these historical conditions may not be well-understood, feasible, or cost-effective, thereby compromising success of restoration actions. USFWS policy (601 FW 3) directs managers to assess not only historical conditions, but also "opportunities and limitations to maintaining and restoring" such conditions. Furthermore, habitat management on refuges should "favor management that restores or mimics natural ecosystem processes or functions to achieve refuge purpose(s)" (620 FW 1 and 601 FW 3).

The refuge was established to restore wetland habitats for migratory waterfowl species. Consequently, future management must attempt to sustain and restore historical wetland ecosystem processes and resources to provide habitat for migratory birds and other wetland-dependent native species. Protection and management of native habitats are primary goals in the draft CCP for CLNWR (USFWS 2014). Recommendations of this HGM assessment, based on the examination of historical ecosystem processes, suggest that wetland and riparian habitats can be restored and/or managed to more functional systems.

All native habitats within the refuge should be protected, restored, and/or managed to: 1) provide resources used and required by native animal species; and 2) increase the resiliency of the ecosystem to future environmental stressors (e.g., climate change). Recommendations resulting from this HGM evaluation address three management adaptation approaches that have been identified as important to increase the resiliency of ecosystems to respond to projected future climate changes. These management adaptations include the following: 1) reducing anthropogenic stresses; 2) protecting key ecosystem features; and 3) restoring ecosystems that have been lost (Baron et al. 2008). Collaboration with other landowners in the Klickitat Subbasin is essential to protect surface and subsurface hydrologic processes that impact CLNWR and to address predicted impacts of climate change. Regional and landscape scale collaboration with multiple partners and disciplines is highlighted in the USFWS climate change strategy (USFWS 2010).

Future management issues that affect timing, distribution, and movement of water on the refuge must consider how, and if, they are contributing to desired objectives of restoring native communities and their ecological processes on the refuge. Additionally, future management of the refuge must seek to define the role of the refuge lands in a larger landscape-scale conservation and restoration strategy for the Columbia Plateau, east Cascade Mountains, and the Pacific Flyway. Given constraints of surrounding land uses, mandates for restoring and managing ecosystem integrity, and opportunities for within refuge and watershed scale conservation, we recommend that the future management of CLNWR should consider the following goals:

1. Protect and restore the physical integrity and hydrologic character of the historical Camas Prairie ecosystem;
2. Restore natural surface water flow patterns and, where necessary, manage water flows to mimic spatially and temporally variable natural hydrological conditions;
3. Restore and/or manage for the diversity, composition, distribution, and regenerating mechanisms of diverse, self-sustaining native wetland and upland vegetation communities in relation to hydrogeomorphic landscape position;
4. Provide key resources that mimic natural patterns of resource availability and abundance during appropriate life history stages.

The following recommendations are suggested to achieve the above ecosystem restoration and management goals for CLNWR.

1. Protect and restore the physical integrity and hydrologic character of the historical Camas Prairie ecosystem.

Geologic landforms, including the CRFB of the Columbia Plateau, volcanic flows from Mount Adams, and sedimentary deposits of glaciofluvial origin created complex groundwater movements into and through the Camas Prairie ecosystem. Wet meadows are considered groundwater-dependent ecosystems (Murray et al. 2003, Boulton 2005). Spatial and temporal variation in water table depth and duration of maximum and minimum water levels in wet meadows controls the distribution of vegetation based on water-stress and oxygen-stress tolerances of individual plant species (Lowry et al. 2011). Although no groundwater monitoring has been completed, ditches constructed to drain wetlands in the Glenwood Valley have likely lowered the groundwater levels throughout Camas Prairie and the historical Conboy Lake. Protecting the shallow alluvial groundwater aquifer from further degradation and restoration of the physical integrity and hydrologic processes are important steps for improving management of wetland habitats at CLNWR. Recommendations that protect and restore the shallow groundwater include the following:

1.1 Apply conceptual models on the hydroecology of wet meadows (e.g., Loheide et al. 2009, Hill and Mitchell-Bruker 2010) to identify groundwater sources, spatial and temporal heterogeneity of flows, and the impact of anthropogenic modifications.

- Monitor water-table configurations (e.g., Patterson and Cooper 2007, Loheide and Gorelick 2007, Hammersmark et al. 2008) to inform a conceptual hydroecologic model specific to the Camas Prairie. Temporal and spatial variability of groundwater flux entering wet meadows is critical to simulate changes in water levels to understand ecosystem responses (Lowry et al. 2010). Natural geochemical and isotopic-tracer techniques (e.g., Rains and Mount 2002, Atekwana and Richardson 2004) can be used to identify the source of groundwater.
- Quantify the interaction of the shallow groundwater and surface water in the Camas Prairie ecosystem.
- Identify the impacts of ditches and water infrastructure development on shallow groundwater flow patterns, including water levels, direction, and magnitude of flow.
- Incorporate climate variables into the conceptual ecological model and link to wetland variables to assess predicted impacts of climate change (e.g., Acreman et al. 2009).

1.2 Re-establish shallow groundwater flow patterns, including spring discharge, hillslope flows, and base flows, into and through the Camas Prairie where possible.

- Avoid constructing additional ditches or excavating borrow areas that intercept groundwater and/or dissect coarse subsurface soil layers, thereby further accelerating subsurface drainage.
- Evaluate alternative water delivery mechanisms (e.g., pipes instead of ditches) to convey water for wetland management objectives in areas where ditches have negative impacts on groundwater flow.
- Continue to fill ditches that intercept areas of groundwater flow and drain subsurface water from wetlands.
- Collaborate with NRCS, soil and water conservation districts, private landowners, and local groups to evaluate the potential to: 1) restore groundwater flows where the water holding capacity of wetland soils has been compromised; and 2) restore surface water flows as described in Recommendation #2.3.
- Pursue acquisition of additional parcels from willing sellers within the approved refuge boundary.

2. Restore natural surface water flow patterns and, where necessary, manage water flows to mimic spatially and temporally variable natural hydrological conditions.

Long-term, annual, and seasonal variation in the hydroperiod (depth, duration, and extent of flooding) of wetland habitats at CLNWR resulted from groundwater interactions with highly variable precipitation and snowmelt runoff in the Klickitat Subbasin. Prior to alterations in topography and water flow patterns, water levels at the refuge rose during the fall as temperatures cooled, evapotranspiration decreased, and precipitation increased. Water content of the snowpack during the winter and weather conditions during the spring and summer largely determined wetland conditions during the growing season and affected recharge of water levels in the shallow groundwater aquifer. Groundwater fluxes and beaver activity maintained surface water in some areas during the dry hot summer months, but most seasonally flooded wetlands were dry by late summer during most years.

Superimposed on the seasonal and annual patterns were long-term fluctuations in precipitation and flooding that created temporally variable multi-decadal wet and dry conditions. This variable long-term, annual, and seasonal flow of water meandered through tributaries of the Chapman Creek, Draper Springs, Frasier Creek, and Outlet Creek Subwatersheds that drained into the Camas Prairie and spread out over a relatively shallow topographic gradient and multiple soil types within the basin before draining through Outlet Creek to the Klickitat River.

Many changes have occurred at CLNWR and within the Middle Klickitat Watershed resulting from alterations in topography and water movement patterns. Most water and wetland infrastructure development expanded on the previous infrastructure that was designed for agricultural purposes. Water diversions for irrigation and drainage of agricultural lands outside of the present day refuge approved boundary have also impacted the surface water flows entering the Camas Prairie. In addition to hydrology, these alterations impacted sediment transport, nutrient dynamics, and invasive vegetation.

The key to maintaining and restoring the abundance, distribution, and diversity of native plant and animal communities at CLNWR is restoring natural long-term, annual, and seasonal dynamics of flooding and drying. Recent advances in understanding of wetland ecology, especially those types with naturally occurring wet and dry annual dynamics, indicate successful long-term restoration of system integrity and productivity requires restoration and/or management of seasonally- and annually-dynamic water regimes, restoration of natural sources and patterns of water flow and movement, and restoration of natural topography (e.g., Laubhan et al. 2012, Heitmeyer et al. 2013). Maintenance and restoration of natural topography and water regimes/flow patterns is also critical to non-wetland habitats on the refuge. Flood pulsing and associated hillslope groundwater fluxes are important drivers of transition zones between riparian and upland habitats (e.g., Middleton 1999, Kovalchik and Clausnitzer 2004).

Water management at CLNWR should seek to mimic natural dynamics by restoring topography and water flow pathways, implementing careful manipulations of water to mimic historical variation in hydroperiods, and installing the appropriate infrastructure to do so, where necessary. Recommendations include the following:

2.1 Identify historical soil surfaces and restore natural topography.

- Evaluate if reed canary grass has trapped sediment and increased organic matter above the historical soil surface of native wet meadows, riparian corridors, and emergent wetlands. This often occurs in sedge meadows and herbaceous riparian corridors where reed canary grass has invaded, resulting in reduced heterogeneous microtopography, fewer associated habitat niches, and altered wetland processes (e.g., Werner and Zedler 2002).
- Remove any accumulated sediment to expose historical wetland soil surfaces and allow seed bank expression. Consider actions in recommendation #3 to restore native vegetation of these areas once hydrologic function is improved.
- Continue to evaluate all levees, roads, and water control structures to determine if they are necessary, or are detrimental, to desired water management. For example, roads may impede surface water flow paths and force previously dispersed runoff through culverts into localized channels, which may increase downcutting through wet meadows (e.g., Cooper et al. 2006).
- Map berm locations and heights to identify where surface water flows are impeded.
- Continue to lower, remove, or modify berms that restrict the flow of surface water. Where feasible, permeable fill in roads

may facilitate restoration of wet meadows (Zeedyk 1996) and other wetland types at the refuge. Hydrologic engineering analyses will be needed to design structural modifications such as constructing spillways, breaches, and low-water crossings in levees and roads.

- Relocate berms necessary for water management along natural elevation contours and soil type boundaries to facilitate management of natural hydrologic conditions.
- Continue to fill ditches that drain surface water from wetland habitats and compromise the water holding capacity of wetland soils.

2.2 *Improve water management in wetland habitats by mimicking historical natural hydroperiods.*

- Modify the existing water management plan for CLNWR to incorporate temporal and spatial variability in hydrologic conditions in managed wetland units. This is an important step to increase long-term productivity of wetland resources.
- Mimic a natural hydrologic cycle in managed wetlands by not filling water to the same level (often referred to as "full pool" or "optimal level") every year.
- Vary the hydroperiod (depth, duration, and extent of flooding) in managed wetlands through time. Temporal variability (including seasonal drying and extended flooding) should mimic naturally dynamic hydrologic conditions. For example, target fill dates, drawdown dates, and water levels within a unit should vary on 5-10 year rotations (or possibly longer) to prevent long-term annually consistent water level management.
- Evaluate the potential for flowage easements with willing landowners where periodic extended surface water flooding impacts private lands.

2.3 *Protect and restore tributary drainages and surface water flow through and into CLNWR.*

- Re-contour in-stream channel characteristics within the refuge considering historical survey notes, GLO maps, and remnant topographic depressions still present on the landscape. For example, USFWS currently plans to redirect surface water flow from an irrigation ditch through a natural channel in the Kelley unit (L. Wilson, USFWS, personal communication).
- Evaluate the potential to restore the historical meanders of Holmes, Chapman, and Bird creeks. Surface water flows could then be managed to mimic temporally variable historical stream flows and restore hydrologic processes through that unit.
- Evaluate the potential to restore historical meanders of Outlet Creek through Troh SW, Troh, Bird Creek NE, and Oxbow units. This may allow for improved water flow and wetland function through these units while still maintaining the existing Outlet Creek. If the existing Outlet Creek drains subsurface water from these units, engineering solutions (e.g., slurry walls) may be required to prevent subsurface drainage.
- Incorporate flood pulsing and disturbance dynamics to restore herbaceous and woody floodplain habitats (e.g., Middleton 1999, 2002).
- Contour stream, ditch, and channel bank elevations to support wet meadow vegetation. Wet meadow vegetation reduces erosion by a factor of 10 compared to similar banks with upland meadow vegetation (Micheli and Kirchner 2002).
- Plug incised stream channels. The method has been used successfully to restore hydrologic processes (e.g., increased frequency and duration of inundation, decreased magnitude of flood peaks, decreased annual runoff) in other high elevation wet meadows (Hammersmark et al. 2008). Stream restoration also increases the spatial distribution of suitable habitat for wetland vegetation (Hammersmark et al. 2010).
- Collaborate with NRCS, other government agencies, local organizations, and private landowners in the Chapman Creek, Draper

Springs, Frasier Creek, and Outlet Creek Subwatersheds to evaluate the potential to restore stream corridors and riparian buffers on lands outside of the acquired parcels of CLNWR that have been drained, channelized, and/or where water holding capacity has been compromised (e.g., Chapman, Holmes, and Bird creeks and associated riparian wetlands).

- Evaluate the potential for flowage easements where stream restoration would negatively impact agricultural operations of private landowners. Flowage easements from willing landowners secure rights and compensate the landowner to flood an area as a result of wetland restoration or for other water management objectives. Ranch operations (e.g., grazing or haying) can typically still be conducted on flowage easements when the area is not seasonally inundated.
- Pursue acquisition of additional parcels with historical stream channels and riparian habitats from willing sellers.

2.4 Collaborate with landowners in the Middle Klickitat Watershed to identify watershed areas that negatively affect erosion and sedimentation.

- Collaborate with NRCS to encourage implementation of soil conservation practices on private agricultural lands.
- Collaborate with state and federal agencies to reduce soil erosion from public lands within the watershed.

3. Restore and/or manage for the diversity, composition, distribution, and regenerating mechanisms of diverse, self-sustaining native wetland and upland vegetation communities in relation to hydrogeomorphic landscape position.

The distribution of native upland and wetland plant communities occurs in response to variations in abiotic factors and interactions among plants and other organisms. Physiological adaptations of plants enable them to colonize, germinate, grow, and successfully reproduce under favorable abiotic (environmental and physical) conditions. Historical land uses and management actions at CLNWR (e.g., wetland drainage, domestic livestock grazing, planting of non-native species, and altered fire regimes) have altered the natural abiotic conditions, ecological processes, and the biological interactions among species.

The complex geologic history, spatial variability of soil types, and large temporal variability of surface water inputs across seasonal, annual, and multidecadal time frames suggest that environmental conditions created a dynamic mosaic of native habitats at CLNWR. However, anthropogenic alterations, mainly drainage and agriculture, decreased the extent of wetland habitats, reduced the magnitude of flood events, and increased the distribution of non-native vegetation. Upland habitats have been impacted by domestic livestock grazing, invasive species, and altered fire regimes. Recommendations to restore natural ecological processes that support self-sustaining native vegetation communities include the following:

3.1 Restore temporally and spatially diverse complexes of native wetland and upland communities with natural water regimes and/or adequate infrastructure to mimic natural hydrologic conditions.

- Restore groundwater fluxes based on results from Recommendation #1.
- Restore surface water connectivity as described in Recommendation #2 to enhance hydrologic processes (e.g., sheetflow, nutrient transport) associated with native plant communities.
- Eradicate (or control to <5% cover) non-native invasive species in all habitat types.
- Collaborate with the Klickitat County Weed Control Board, other agencies, and private landowners to control noxious weeds on public and private lands within the Middle Klickitat Watershed to reduce seed sources and propagule dispersal to refuge lands.
- Implement management strategies that mimic natural disturbance regimes (e.g., flooding, drought, prescribed fire) to help sustain native habitats after they are restored.

3.2 Re-design and/or rehabilitate existing wetland units (not restored to natural conditions) in relation to topographic and hydrogeomorphic landscape position to improve *wetland management capabilities and enhance habitat quality.*

- Evaluate existing management units to identify modifications that may be needed to enhance abiotic conditions required to produce resources for wetland-dependent species.
- Manage wetland units as complexes of habitat types based on suitability of specific units to provide diverse resources needed to meet the annual cycles needs of animal species using the refuge during different seasons and over long-term periods of the wet-dry cycle.
- Evaluate wetland units with multiple soil types to determine the most appropriate water management strategy. For example, the Aspen and Conboy Lake units include areas of Conboy clay loam and Grayland silty clay loam. Water-level management that promotes desirable vegetation communities on Conboy clay loam soils may not be the best management scenario for native vegetation communities on Grayland silty clay loam. In contrast, the same water management across these two soil types may create desirable interspersion of habitat types. It is therefore necessary to evaluate habitat responses across multiple soil types on a case by case basis.
- Reconfigure wetland unit boundaries that cross multiple soil types to improve effectiveness of water management actions, as needed. Low-profile berms should be placed along topographic contours and soil type boundaries to maximize management potential.

3.3 *Manage wetland areas for natural seasonal, annual, and long-term water dynamics.*

- Continue monitoring recently installed water level loggers to quantify hydroperiod characteristics of managed wetland units.
- Change or modify water-control infrastructure in units, if needed, to allow flexibility for seasonally and inter-annually variable water regimes.
- Manage wetland areas for different stages of succession to the extent possible to address life history needs of wetland-dependent species. This will allow annually consistent resources to be provided, while managing for temporally variable water regimes critical for productive and functional wetland habitats.
- Manipulate water levels to enhance availability of food and cover resources.

3.4 *Restore wet meadow habitats.*

- Remove reed canary grass from areas of historical wet meadow communities. This may require using multiple management techniques, including multi-year applications of a selective herbicide (Annen et al. 2005, but see Healy and Zedler 2010), selective herbicides with pretreatments (Annen 2008, 2010), and/or a combination of physical and chemical controls coupled with water-level management (Kilbride and Paveglio 1999, Reinhardt and Galatowitsch 2004, Lavergne and Molofsky 2006). Effectiveness of removal techniques may in part be dependent on the above ground density and underground nutrient and energy reserves of reed canary grass.
- Limit conditions suitable for the germination and spread of invasive species during restoration and management activities to prevent establishment or expansion of undesirable species. For example, reed canary grass exhibits a phytochrome-mediated germination response typical of pioneering species and readily establishes from seed after canopy disturbance (Lindig-Cisneros and Zedler 2001). Reed canary grass seedlings accumulate biomass faster and are more tolerant of hydrologic stressors than other native wetland plant species (Kercher and Zedler 2004) and spread quickly after germination.
- Evaluate the phenology of reed canary grass growth to see if haying can be used as an interim management tool to reduce or prevent seed production. The potential for mowing may be limited in areas that are too wet or used by nesting sandhill cranes. However, improved water delivery infrastructure (See Recommendation #3.3) may increase flexibility to allow for intensive

management actions. In addition, short term reductions in sandhill crane productivity may be outweighed by long term improvements in habitat conditions and should be evaluated on a site-specific basis.

- Restore seasonal sheetwater flows into wet meadow habitats so that short duration shallow inundation is created by removing obstructions to water flow.
- Provide temporally variable annual water management if natural inundation patterns in wet meadow areas cannot be restored and manage water flow across wet meadows in natural sheetflow patterns.
- Vary surface water flooding where 1 July is the current drawdown initiation date to mimic natural conditions that occurred during historical wet cycles. The same flooding regime should not be implemented on a management area every year because this consistency will ultimately compromise long-term wetland productivity.
- Implement drawdowns or allow natural water-level fluctuations to remove and recycle plant biomass and release bound nutrients, provide natural regeneration substrates, and support high (but annually dynamic) primary and secondary productivity on a regular basis.
- Prepare a vegetation management plan for wet meadows that can emulate natural vegetation species composition and seasonal structure.

3.5 *Restore semi-permanently flooded tall emergent and open water/SAV wetlands within the historical Conboy Lake.*

- Manage open water communities for pioneering, desirable SAV species (e.g., sago pondweed) with high nutrient values that are adapted to disturbance. Avoid drawdowns that expose bare substrate during hot summer temperatures to reduce the potential for germination and spread of cattail.
- Manage seasonally and annual variable water levels to prevent formation of decadent stands of robust emergent vegetation.
- Conduct water-level drawdowns to promote desirable plant species considering life history strategies (e.g., germination requirements) and to increase decomposition and nutrient turnover rates.
- Implement drawdowns to remove surface water and soil water within the root zone of plants to reduce the extent of tall emergent vegetation if it becomes too decadent. Removal of surface water only is not sufficient to stress wetland plant species that are flood tolerant and have large underground biomass capable of storing large quantities of carbohydrates and nutrient reserves (e.g., *Typha*). Multiple management treatments following removal of surface and subsurface water may be required for effective control.

3.6 *Restore native upland meadows and forest communities.*

- Apply adaptive ecosystem management concepts that emphasize sustainability of land systems (e.g., Hessburg and Agee 2003).
- Restore and manage for herbaceous and shrubby understory species that historically occurred in upland habitat types.
- Thin dense stands of ponderosa pine to restore upland bunchgrass meadows and open ponderosa pine habitats (White 2009) on appropriate landforms and soil types. Understory trees and shrubs were typically absent from this vegetation community (e.g., Spray 1875). Target tree density and size classes are suggested by White (2009).
- Create snags in open ponderosa pine habitats at desired densities for landbirds (Altman 2000, White 2009).
- "Underburn" ponderosa pine habitats with prescribed fire, as needed, after they are thinned to remove fuels and kill small trees (White 2009).
- Maintain mixed pine-fire forests on mountain foothills and canyon side slopes along the southern and western boundaries of CLNWR. Late succession stands of this vegetation community are in good condition (White 2009). Historically, this vegetation community occurred on a relatively small

area of the approved refuge boundary (see Fig. 18).

4. ***Provide key resources that mimic natural patterns of resource availability and abundance during appropriate life history stages.***

CLNWR cannot expect to provide resources for all life-cycle events of all species, but these HGM-based recommendations will help restore natural systems and resources for priority species in relation to state, regional, and flyway resources. Priority species have been identified in the draft CCP (USFWS 2014). Natural patterns of resource availability need to be identified in the context of historical wetland and upland ecological processes in order to support productive vertebrate populations.

Oregon spotted frogs were identified as a priority species, and survived in the Camas Prairie ecosystem despite extensive drought conditions (coupled with wetland drainage) during the 1930s, 1940s, 1977, and late 1980s. Although anthropogenic alterations to native habitats contributed to long-term population decreases, Oregon spotted frogs seem to have adaptive mechanisms allowing them to persist during periods of drought.

The role of tadpoles in aquatic food webs is very complex and poorly understood (see Schiesari et al. 2009). In addition to temperature and hydroperiod, survival and growth rates of anuran tadpoles has been related to quantity, quality (e.g., N:P ration, C:N ratio, soluble phenolics), and availability of litter, (Capellán and Nicieza 2007, Rittenhouse 2011, Cohen et al. 2012), all of which are directly or indirectly affected by hydrology. Because allogenic hydrologic disturbances are one of the main drivers of wetland function and processes (Mitsch and Gosselink 2000), most human-induced hydrologic alterations, which include annually consistent water level management, negatively impact wetland plant communities (see summary in Cronk and Fennessy 2001).

Oregon spotted frog egg mass counts were high during 1998 and 1999, an above average wet period that followed drought conditions from the mid-1980s to mid-1990s. Drought conditions occurred again from 2000 to 2009. Above average wet conditions resumed during 2010; however, an increase in egg masses were not observed during this wet period. Therefore, managing annually consistent water levels to maximize breeding habitat for Oregon spotted frogs every year may compromise long-term population growth by reducing wetland productivity. Short-term losses in egg mass and juvenile survival during drought conditions (either natural or managed) may be outweighed by long-term increased productivity due to increased nutrient cycling following periods of drought (or managed drawdown) and reflooding (e.g., Brinson et al. 1981, Murkin 1989, van der Valk 2000, Sánchez-Carrillo and Álvarez-Cobelas 2001, Bostic and White 2006).

Recommendations to provide resource needs include the following:

- Manage wetland habitats to provide resources for species of concern in Washington, while considering spatial and temporal variability of productive wetland habitats.
- Manage upland habitats to provide structure and cover required for grassland and forest obligate species.
- Provide refuge areas that include multiple habitat types and minimize human disturbance during key life history stages.
- Evaluate public use programs to reduce and/or eliminate disturbance during key life history stages.
- Ensure that management and research actions minimize disturbance during key life history events, as much as possible.

FIELD APPLICATION OF HGM INFORMATION FOR SITE-SPECIFIC PLANNING

On-site field evaluations will be needed to identify potential actions, limitations, and solutions to implement recommendations outlined in this report and prepare step-down management and restoration plans for specific management units at CLNWR. At the site-specific scale, this report identifies: 1) information needed to determine what vegetation communities were present at a site; 2) if and how these communities have been altered; and 3) information gaps, that when filled, will further enhance the refuges' knowledge of historical vegetation communities and wetland processes. For example, the GIS databases assembled in this report provide information on geomorphology, soils, and to some degree the hydrology of the site. Unfortunately, detailed elevation, groundwater characteristics, and stream flow data within the Glenwood Valley are not currently available, but if obtained in the future, can be used to further refine and delineate different hydroperiods within the historical wet meadow-marsh community modeled in this report (e.g., temporarily and seasonally flooded wet meadows, semi-permanently flooded emergent marsh).

The HGM evaluation for CLNWR asks four basic sets of questions that can guide tract assessments and help managers prepare implementation plans:

1. What were the historical (Pre-settlement) communities on a tract, what landscape features were associated with these communities, and what abiotic and biotic processes sustained them?

2. What changes have occurred from the historical condition, both in landform and ecological processes?

3. What communities can be protected and sustained (if not altered), restored, and/or managed for to provide resources for all species? In other words, what is the new desired community?

4. What physical and biological changes are needed to create, restore, manage, and sustain the new desired community while incorporating natural patterns of variation and increased resiliency to adapt to changing conditions?

The HGM matrix (Table 4) developed as part of this report helps managers identify what physical features (e.g., soil type) and ecological processes (e.g., flooding duration) sustained historical vegetation communities at a location. Successful restoration of a community type depends on restoring the appropriate processes on the correct landform. If anthropogenic modifications prevent complete restoration of ecological processes, management actions can mimic those processes. However, correctly placed infrastructure and adequate resources (e.g., staff time, funding) are required for management actions to be effective.

A multi-agency, interdisciplinary team, including, but not limited to biologists, wetland ecologists, soil scientists, hydrologists, geomorphologists, and maintenance staff has been effectively used to develop site-specific restoration and management plans at other National Wildlife Refuges and State conservation areas. Wetland reviews, originally developed in Missouri and later expanded and fine-tuned for other regions (e.g., the Rio Grande ecosystem, wetland areas in southeast Idaho) effectively incorporate a diverse knowledge of abiotic and biotic factors that are important to understanding ecosystem function, providing the necessary resources at the appropriate time to support abundant animal populations, and guiding future restoration and management actions.

Lisa Wilson

MONITORING AND SCIENTIFIC INFORMATION NEEDS

Future management of CLNWR should include routine monitoring and management-oriented research to determine how ecosystem structure and function are changing, regardless of whether restoration and management options identified in this report are undertaken. Ultimately, the success in restoring and sustaining communities and ecosystem functions/values at the refuge will depend on how well the physical and hydrological integrity of the shallow groundwater is protected as well as how key ecological processes and events, especially naturally variable seasonal and annual surface water flows, can be restored or mimicked by management actions. Recommendations in this report address these critical issues and propose restoration of fundamental ecological processes that drive ecosystem function. Nonetheless, uncertainty exists about the ability to make some system changes considering constraints associated with existing land uses and scattered parcel ownership in the historical Camas Prairie. Also, effective techniques for controlling invasive plant species are not entirely known and information on life-history requirements of some native wetland plant species is lacking.

Future management actions at CLNWR should be done in an adaptive management context where: 1) predictions about resource responses are articulated through objectives (e.g., reduced abundance of reed canary grass, increased availability of high quality food resources) relative to specific management actions (e.g., chemical and mechanical control, temporally variable drawdowns); and then 2) follow-up monitoring is conducted to evaluate ecosystem responses of plant and animal communities to management actions.

Many recommendations in this report will increase the resiliency of the refuge by allowing it to better adapt to future climate change. Long-term monitoring of the key ecological processes can inform future management challenges related to climate change. Monitoring and adaptive management implemented to meet ecosystem goals are consistent with the USFWS's Strategic Habitat Conservation (SHC) and climate change strategies (National Ecological Assessment Team 2006, National Technical Assessment Team 2008, USFWS 2010).

The availability of historical hydrologic and vegetation data for CLNWR (e.g., long-term modeled climate data, Klickitat River stream discharge, GLO survey notes and maps) greatly enhanced the ability of this HGM evaluation to identify potential management options for the refuge. However, other important data and scientific information needed to more precisely understand HGM relationships and management options are not available. The most important missing scientific information needs include the following: 1) hydrologic data for the shallow groundwater fluxes that can be used in hydroecologic models; 2) streamflow data for creeks flowing into the Glenwood Valley; 3) detailed elevation data; and 4) historical photographs and maps from the 1890s to the 1960s that further identify pre-drainage and pre-refuge development habitat conditions. If these data become available, the HGM relationships, maps, and recommendations provided in this report likely can be refined. Especially critical scientific information and monitoring needs for the refuge are identified below.

KEY BASELINE ABIOTIC DATA

Additional baseline abiotic and biotic data can be used to advance multiple scientific information gaps identified in the recommendations. Certain important site-specific data currently lacking and needed to implement effective adaptive management at CLNWR include the following:

- Detailed hydrologic data for the shallow groundwater that can be used to model spatially and temporally variable groundwater levels, direction, magnitude of flow, and interaction with surface water (see Recommendation 1.1).
- Streamflow data for creeks flowing into the Glenwood Valley.
- Soil surveys to identify inclusions present at a finer scale than currently mapped.
- Soil surveys to identify if and where sedimentation has buried historical wetland soils (see Recommendation 2.1).
- Detailed topographic surveys (e.g., LiDAR).

RESTORING OR MANAGING FOR NATURAL WATER REGIMES AND FLOW PATTERNS

Several physical and management changes are recommended to help restore or enhance natural topography, water flow, and flooding dynamics (see Recommendations #2 and #3). Most changes involve restoring at least some natural surface water flow from tributaries and to manage wetland units for more seasonally- and annually-dynamic flooding and drying regimes. The following monitoring will be important to evaluate the effects of these changes if implemented:

- Continued annual monitoring of water use for refuge areas including source and delivery mechanisms or infrastructure.
- Continued annual monitoring of the depth and duration of surface water in management units.
- Compile existing hydrologic data collected from managed refuge units into an electronic format.
- Expand existing water level monitoring to assess the extent of flooding and drying at different sites (e.g., stratified by elevation, soil type, etc), and relationships with non-refuge water and land uses. This will require a series of staff gauges in managed, restored, and remnant wetland habitats, inflows and outflows, groundwater wells, and piezometers tied to elevation.
- Monitoring soil moisture in relation to controlled and uncontrolled inputs as well as environmental variability associated with wind, clouds, residual vegetation, soil texture, and organic matter is relevant for assessing optimal germination conditions for native species and management of productive habitats.
- Monitor water quality at the refuge.

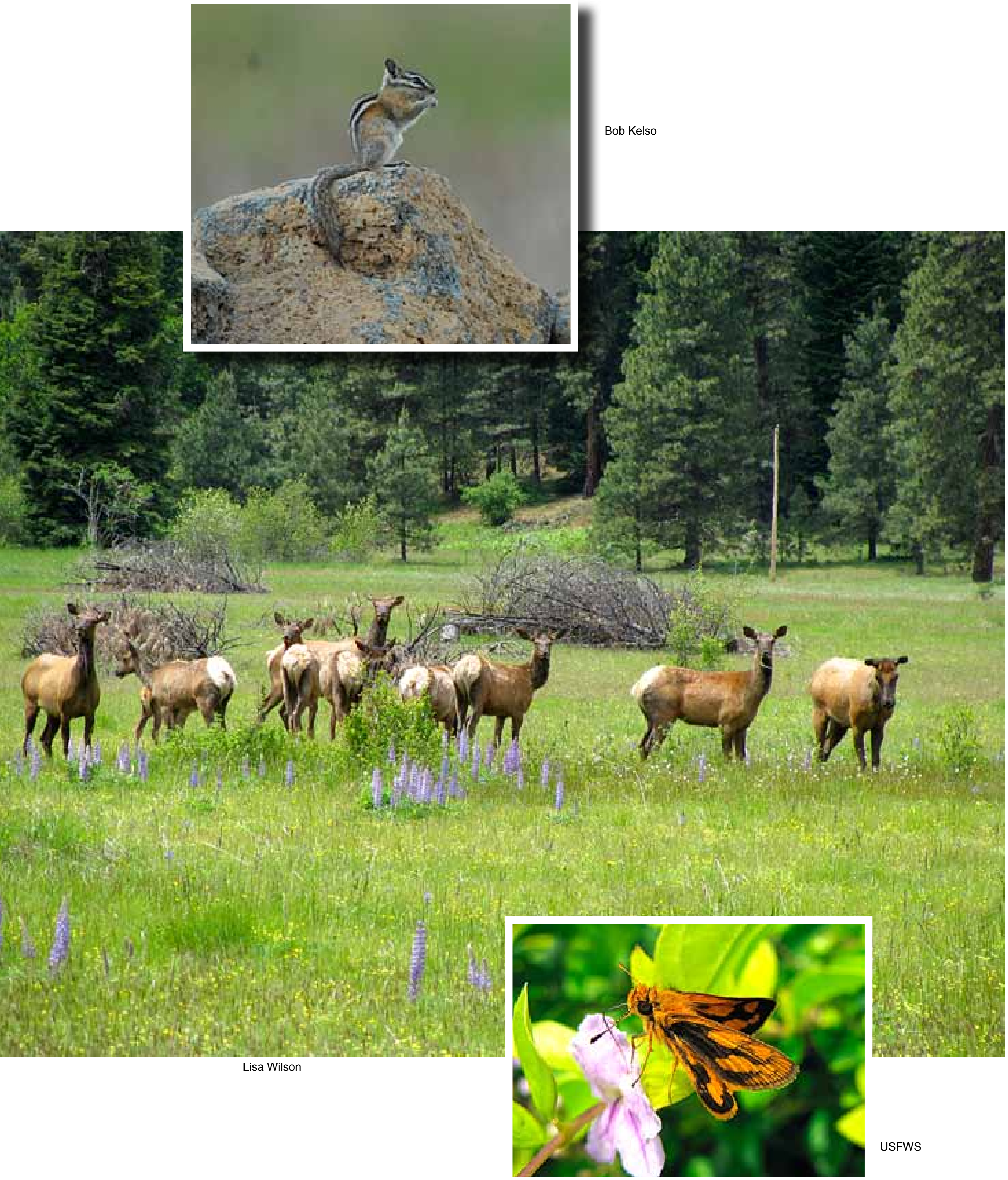
LONG-TERM CHANGES IN VEGETATION AND ANIMAL COMMUNITIES

Recent monitoring of plant and animal communities and populations on the refuge has been confined mostly to a few priority species such as Oregon spotted frogs and plant species of concern. Although historical trend data are most readily available for waterfowl, analyses that assess linkages among populations, habitat use, and availability of resources are lacking. Data on other animal species are also limited and recent waterfowl population data are not available. Monitoring certain species may be especially important because they are indicators of community status, habitat condition, or species of concern, introduced or invasive, and either increasing or decreasing over longer terms at unusual rates. In addition to determining current populations of species, long-term surveys are needed to understand changes over time and in relation to management activities. Important surveys for plants and animals include the following:

- Distribution and composition of major plant communities and species over time, including expansion or contraction rates of invasive plant species, relative to refuge management and abiotic conditions.
- Associations between native and invasive wetland plant species, physical conditions (e.g., soil type, hydrology), and management activities (e.g., water management, soil disturbance).

- Survival, growth, and regeneration rates of native and introduced species in wet meadow and upland habitats following disturbance or management actions.
- Abundance, chronology of life history events, habitat use and availability, juvenile and adult survival, and recruitment of bird species.
- Abundance, chronology of life history events, and habitat use and availability of Oregon spotted frogs.
- Occurrence and abundance of other animal species.
- Occurrence, abundance, and availability of aquatic invertebrates as a food resource for waterbird species.

Bob Kelso



Bob Kelso

Lisa Wilson

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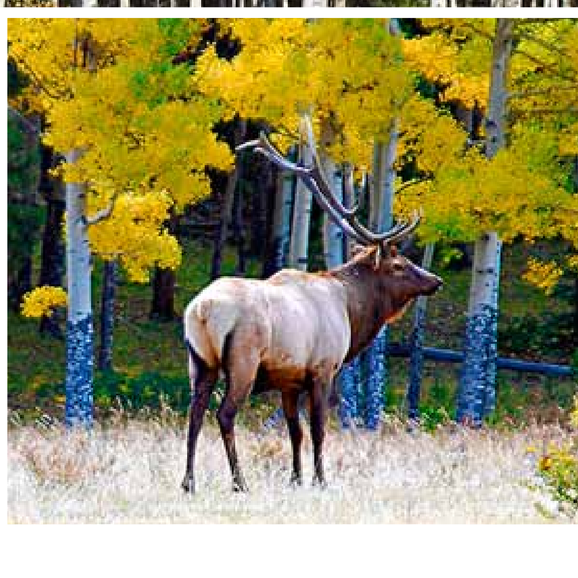
Lisa Wilson

Lisa Wilson



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